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# MASTSAS – Mast Structural Analysis Software

## *Examples Manual*

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*Contract Number: W7707-021754/001/HAL*

*Contract Scientific Authority: Dr. M. J. Smith, (902) 426-3100 x383*

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**Defence R&D Canada – Atlantic**

Contract Report
DRDC Atlantic CR 2004-089
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Canada

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# Abstract

MASTSAS (MAST Structural Analysis Software) is a special-purpose, PC based computer program for rapid finite element modeling of warship mast structures. The MASTSAS software was developed under contract to DRDC Atlantic, using its HOOD (Hierarchical Object Oriented Database) toolkit. This Examples Manual, one of a series of three manuals documenting the MASTSAS software, provides a set of sample models and analyses that demonstrate the capabilities of the MASTSAS system.

# Résumé

MASTSAS (MAST Structural Analysis Software ou logiciel d’analyse des structures de mâts) est un programme spécialisé pour PC, destiné à la modélisation rapide par la méthode des éléments finis des structures des mâts des navires de guerre. Le logiciel MASTSAS a été développé par un entrepreneur lié par contrat à RDDC Atlantique, au moyen de la boîte à outils HOOD (Hierarchical Object Oriented Database ou base de données hiérarchique orientée objet) de cet organisme. Le présent guide d’exemples, qui fait partie d’une série de trois manuels qui documentent le logiciel MASTSAS, propose un ensemble d’analyses et de modèles d’exemple qui font la démonstration des capacités du système MASTSAS.

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# Executive summary


## Introduction

Under the FELEX (Frigate Equipment Life Extension) project, a redesign of the HALIFAX class main mast is being considered for its mid-life refit. Since 1999, DRDC Atlantic has been developing capabilities for efficient modelling of warship mast structures, principally through the development of the MASTSAS software, so as to aid the engineering analysis of new or existing mast designs.

## Principal Results

The MASTSAS software provides capabilities for efficiently modeling mast structures typical of warships. These include lattice masts (currently used on CF vessels), and enclosed, or plated, mast designs. Metallic and composite structural materials are supported. The report provides an Examples Manual for the MASTSAS software. It describes a set of sample models and analyses that demonstrate the capabilities of the MASTSAS system.

## Significance of Results

Engineering assessments of new or existing mast designs can be performed with MASTSAS in an efficient manner. The tools provided in MASTSAS and the design features of the software allow changes in the design to be assessed more rapidly than with a generic FE modelling package. One of the example models described in this report is the existing HALIFAX class main mast. This model will be a valuable asset for future structural analysis work.

## Future Plans

The development of the software was completed in 2003. No further development is planned at this time, although some modification may be required for the FELEX project.



Brennan, D. P., Rushton, P. A., and Koko, T. S. (2004). MASTSAS – Mast Structural Analysis Software. Examples Manual. DRDC Atlantic CR 2004-089. Defence R&D Canada – Atlantic.

# Sommaire


## Introduction

Dans le cadre du projet FELEX (Frigate Equipment Life Extension ou prolongation de la vie de l’équipement des frégates), on envisage la réingénierie du grand mât des navires de la classe HALIFAX, pour leur remise à niveau de mi-vie. Depuis 1999, RDDC Atlantique élabore des capacités permettant de modéliser de façon efficace les structures des mâts des navires de guerre, principalement grâce au développement du logiciel MASTSAS, afin de faciliter l’analyse technique des nouveaux modèles de mât ou des modèles de mât existants.

## Principaux résultats

Le logiciel MASTSAS est doté de fonctionnalités qui permettent de modéliser de façon efficace les structures de mât que l’on retrouve sur les navires de guerre. Ces structures comprennent les mâts-treillis (utilisés actuellement sur les navires des FC), ainsi que des modèles de mât à structure fermée ou composée. Ce logiciel prend en charge les structures en matériau métallique ou composite. Le rapport présente un Guide d’exemples pour le logiciel MASTSAS. Il décrit un ensemble d’analyses et de modèles d’exemple qui font la démonstration des capacités du système MASTSAS.

## Portée

MASTSAS permet d’effectuer une évaluation technique efficace des nouveaux modèles de mât ainsi que des modèles existants. Les outils intégrés à MASTSAS ainsi que les fonctions de conception du logiciel permettent d’évaluer les changements apportés à la conception, plus rapidement qu’avec un logiciel de modélisation par éléments finis général. Un des modèles d’exemple décrits dans ce rapport concerne le grand mât des navires existants de la classe HALIFAX. Ce modèle s’avérera un outil précieux pour les travaux ultérieurs d’analyse des structures.

## Futures recherches

Le développement du logiciel a été achevé en 2003. Pour le moment, on ne prévoit pas d’autre travail de développement, bien qu’il se peut que certaines modifications doivent être apportées pour le projet FELEX.



Brennan, D. P., Rushton, P. A., et Koko, T. S. (2004). MASTSAS – Mast Structural Analysis Software. Examples Manual. RDDC Atlantique CR 2004-089. R&D pour la défense Canada – Atlantique.

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# 1. INTRODUCTION

## 1.1 Background

MASTSAS (acronym for MAST Structural Analysis Software) is a special-purpose, PC based computer program for rapid finite element modeling of masts. The MASTSAS software development uses the Object Oriented Programming (OOP) technology, and is built on the HOOD (Hierarchical Object Oriented Database) toolkit [1]. MASTSAS objects inherit from HOOD base classes and thus they inherit all the functionality of the base classes such as searching, I/O, setting privileges, as well as graphics functionality such as drawing and picking.

MASTSAS provides the following capabilities and features:

- Rapid geometric modeling of lattice, enclosed or combined lattice-enclosed masts;
- Rapid finite element modeling of the various types of masts;
- Interface with DSA-VAST and ANSYS finite element packages;
- Special-purpose post-processing to verify integrity of mast structures, based on strength, stability and vortex shedding criteria;
- Capabilities for defining and applying various types of loads (wind, blast sea load, self weight, and underwater shock) to mast structures;
- Capabilities for modeling masts made of metallic or composite materials;
- Provides a user friendly, PC based modeling environment

## 1.2 MASTSAS Documentation

The MASTSAS software documentation is presented in three volumes as follows:

- Volume 1 contains the User's Manual that provides guidance on the use of the software system
- Volume 2 contains the Reference Manual that provides the theoretical foundations and details on the capabilities offered by the program.
- Volume 3 (this volume) contains the Examples Manual that provides sample problems/models generated by the MASTSAS system.

## 1.3 Organization of this Manual

The remainder of this manual is organized as follows:

Chapter 2: Demonstrates the construction of a simple lattice mast, including the creation of main/auxiliary masts and yardarms, equipment attachment, application of boundary conditions and loads, as well as generation of the finite element mesh. Finally, a vibration analysis is performed on the mast model.

Chapter 3: Presents a static analysis of a simple enclosed mast structure subjected to environmental loading. Common features such as generation of the main mast, boundary conditions, applied loading, and finite element mesh are re-iterated. Additional features such as interior panel cut-outs are introduced.

Chapter 4: Illustrates model development for the Event Dicethrow Mast. Analyses performed include natural frequency analysis, static analysis, and blast analysis, wind loading and ship motion. Specialized features permitting deletion of individual braces and specification of gusset plate masses are introduced.

Chapter 5: Demonstrates modeling and analysis capabilities for the highly complex CPF Mast. The mast is not only analyzed for natural frequencies, but also response to wind loading, and ship motion under a specified sea state. Specialized features for default gusset sizing and vertical reorientation of interpolated yardarm cross-sections are illustrated.

Chapter 6: Presents the software capabilities for an enclosed steel mast. This mast, which is based on a design used by the Royal Netherlands Navy, is analyzed for natural frequencies and response to wind loading. The addition of cross-section cutouts with local offsets is reviewed.

Chapter 7: Illustrates model development for an enclosed composite mast based on a US Navy design. MASTSAS features for stiffened panel and composite material modeling are thoroughly demonstrated. An eigenvalue analysis is performed on the enclosed mast model.

Throughout the first two examples, a step-by-step procedure will be used to illustrate the basic modeling features of MASTSAS. Description of the remaining example problems will be limited to the information necessary to generate the mast model and illustration of any specialized or notable features not previously discussed.

# 2. VIBRATION ANALYSIS OF A SIMPLE LATTICE MAST (EXAMPLE 1)

## 2.1 Problem Description

The first example problem describes the natural frequency analysis of a simple lattice mast. Covered topics include the generation of mast geometry (including main and auxiliary trunks, yardarms, and equipment), application of boundary conditions and loads, generation of the corresponding finite element model, and running the vibration analysis.

## 2.2 Geometry

### 2.2.1 Creating the Main Trunk

The main trunk of the mast structure will be generated based on the following requirements:

- main mast structure (4-sided) is 10m in height (oriented vertically)
- main mast structure consists of 3 main cross sections located at 0m, 7.5m, and 10m (i.e., 2 main bays)
- base cross section measures 3.5m x 3.5m
- top cross section measures 2.5m x 2.5m
- lattice type ‘A’ is applied between major cross sections
- main mast members are constructed of circular steel sections, with an inner and outer radii of 75mm and 125mm, respectively
- lower bay is subdivided into three equally spaced bays

Execution of the above steps is shown in Figure 2.1 through Figure 2.9 below.

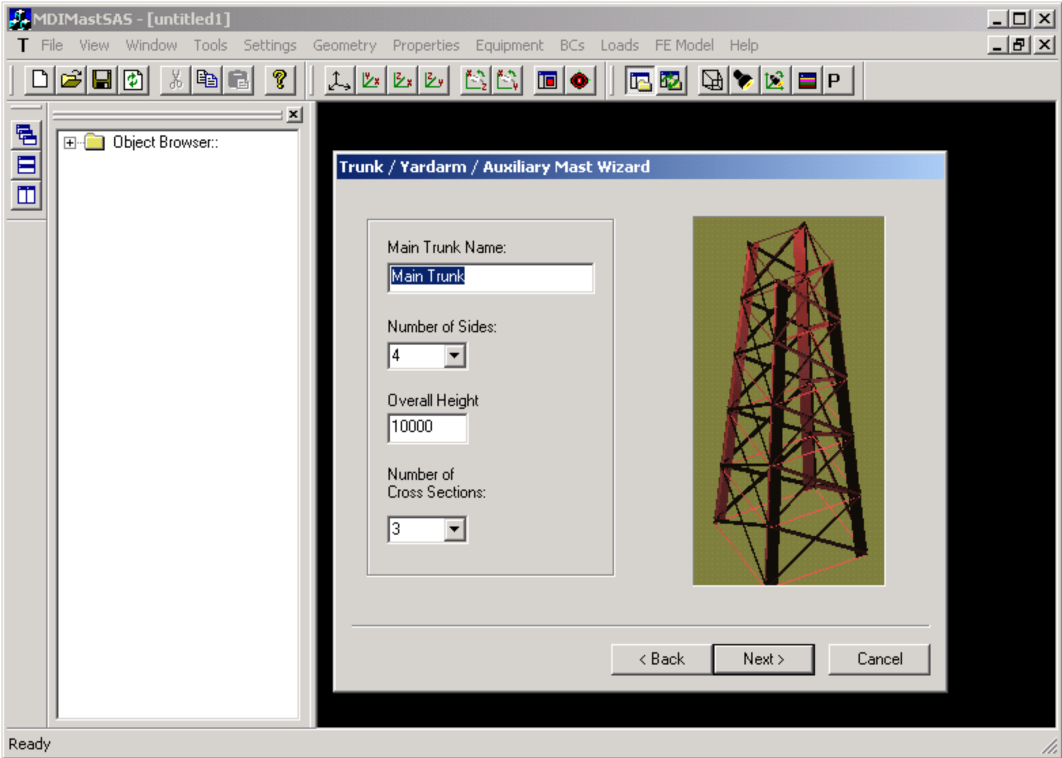



**Figure 2.1: Creating the main mast section (simple lattice mast)**

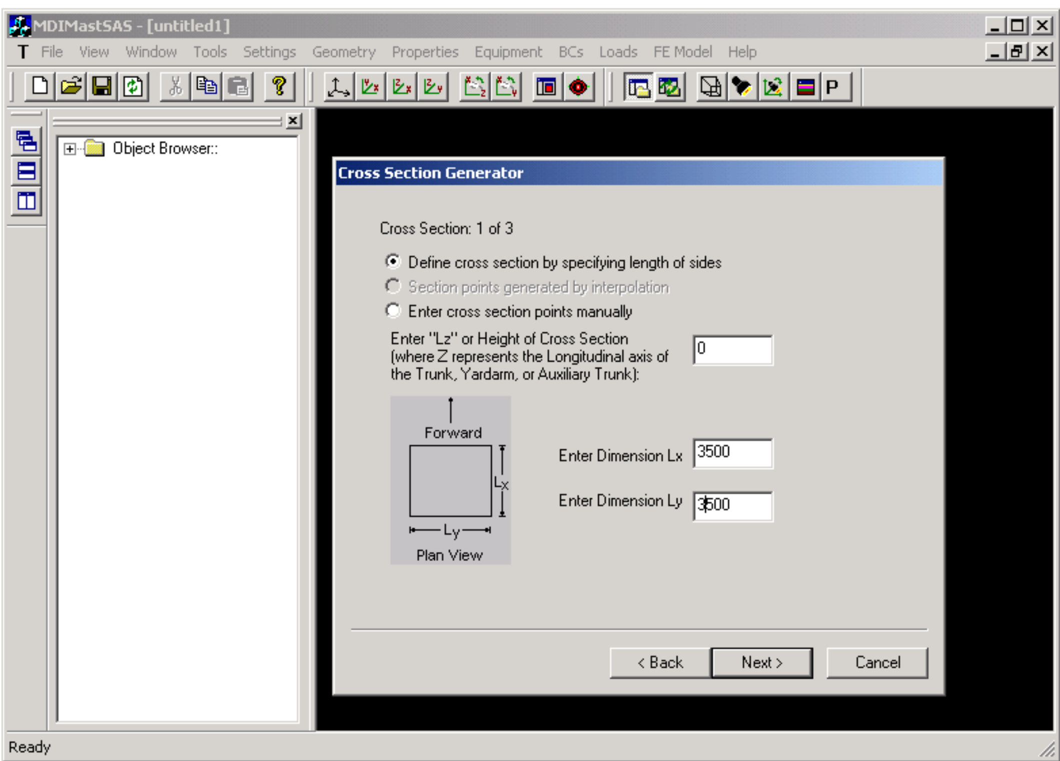



**Figure 2.2: Defining cross section (1 of 3) information for main mast section**

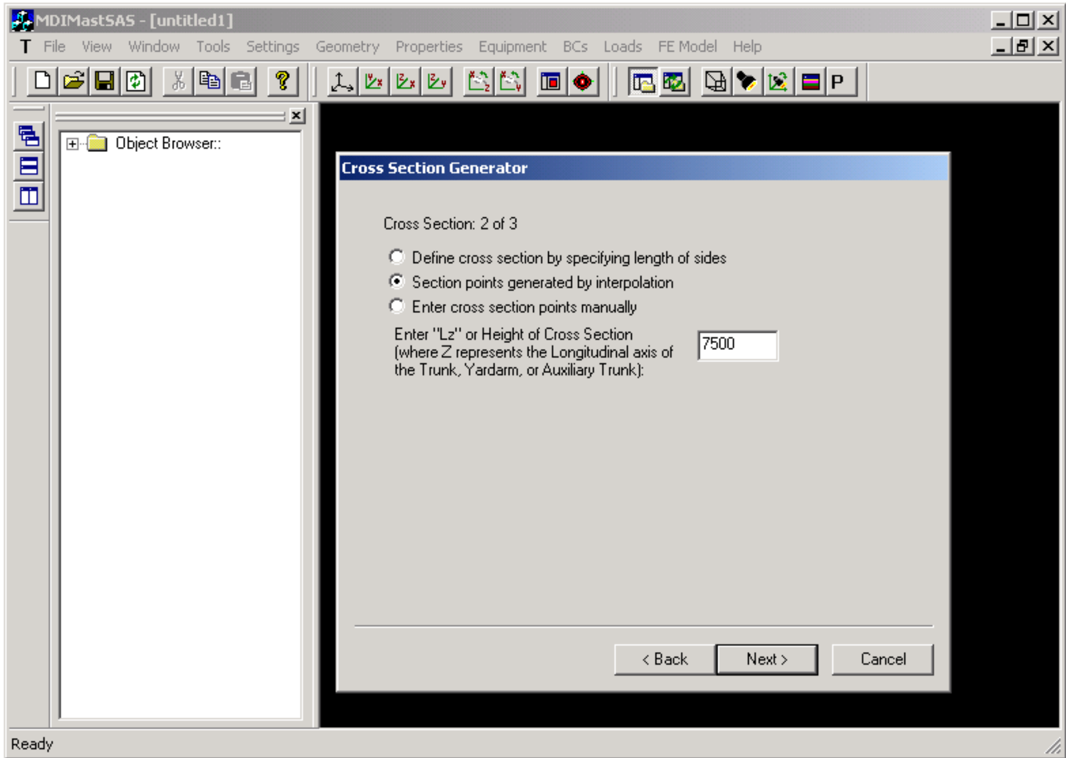



**Figure 2.3: Defining cross section (2 of 3) information for main mast section**

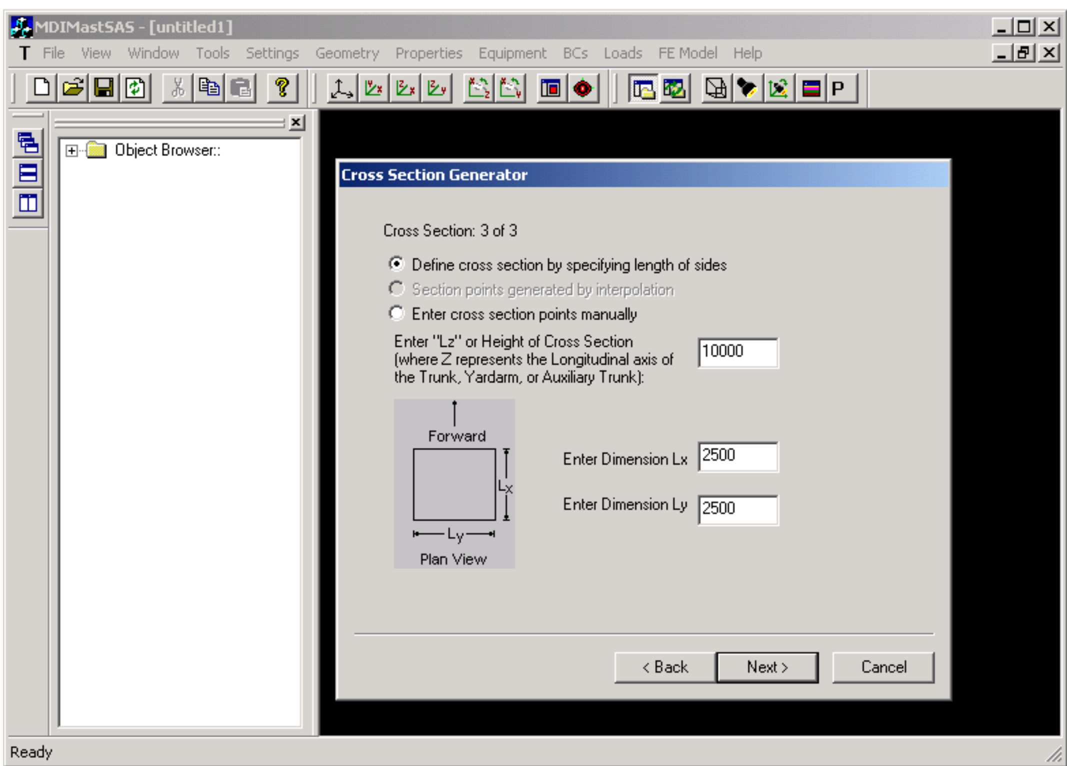



**Figure 2.4: Defining cross section (3 of 3) information for main mast section**

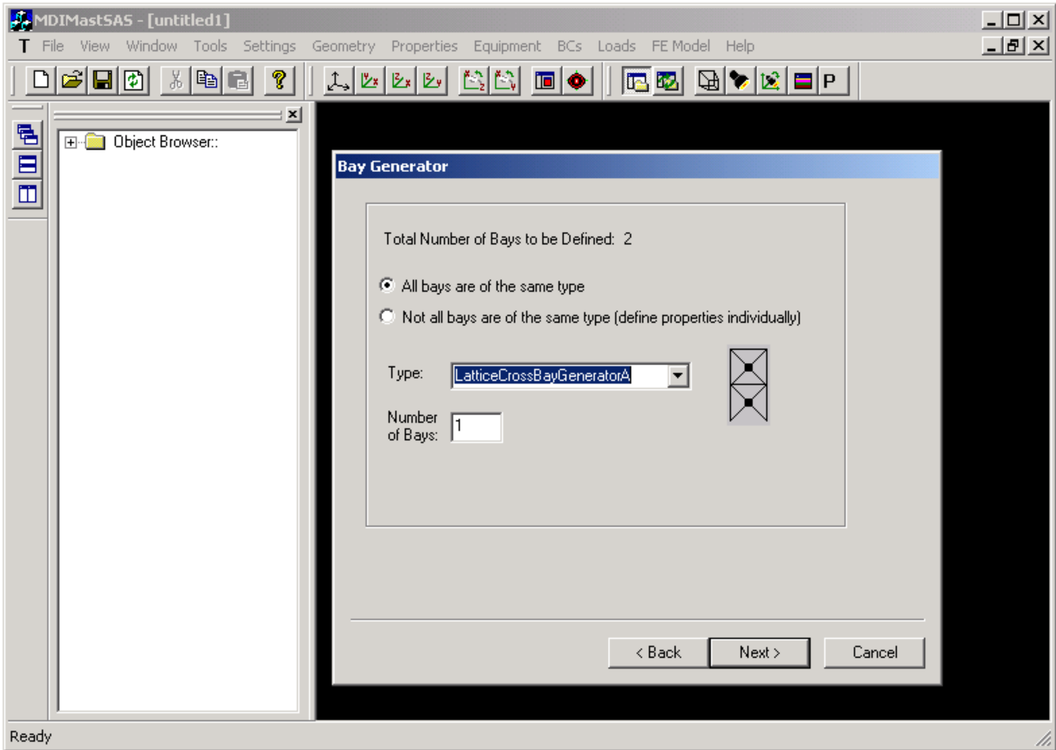



**Figure 2.5: Bay generation for main mast section (simple lattice mast)**

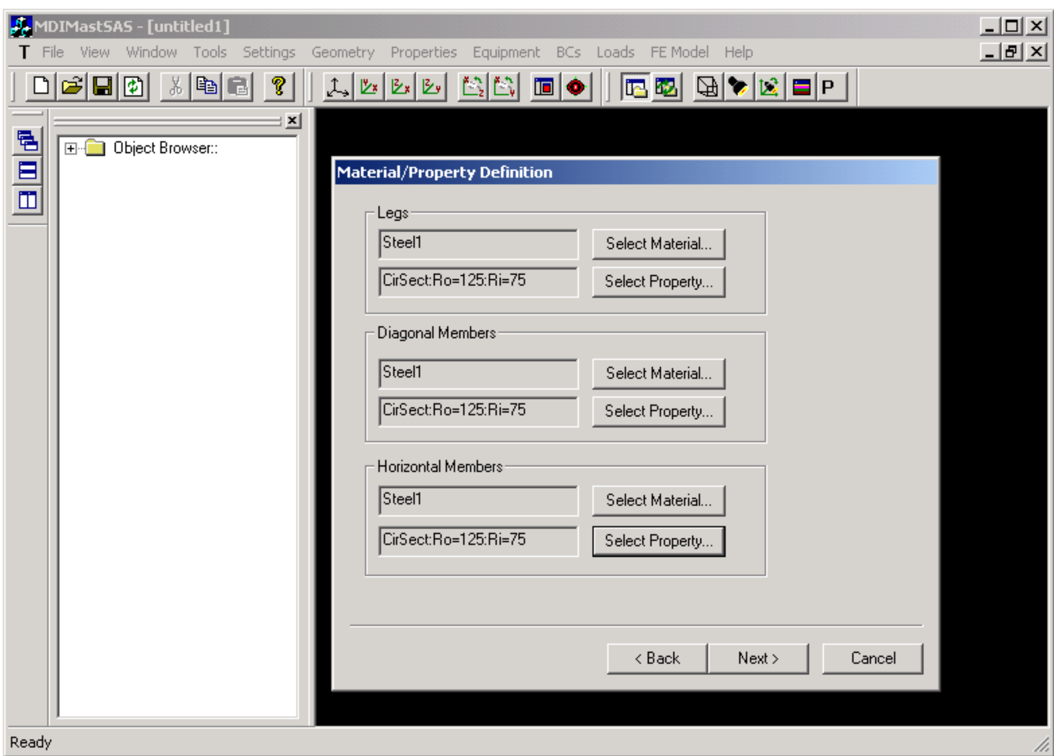



**Figure 2.6: Definition of material properties for main mast section (simple lattice mast)**

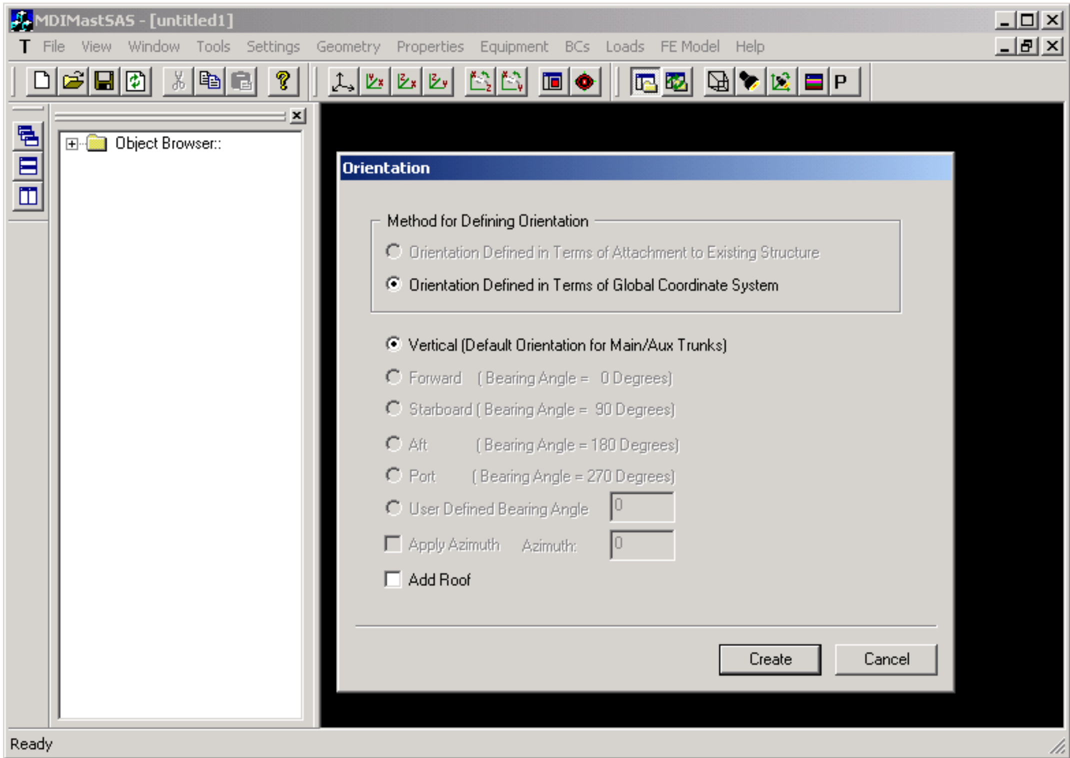



**Figure 2.7: Defining orientation of main mast section (simple lattice mast)**

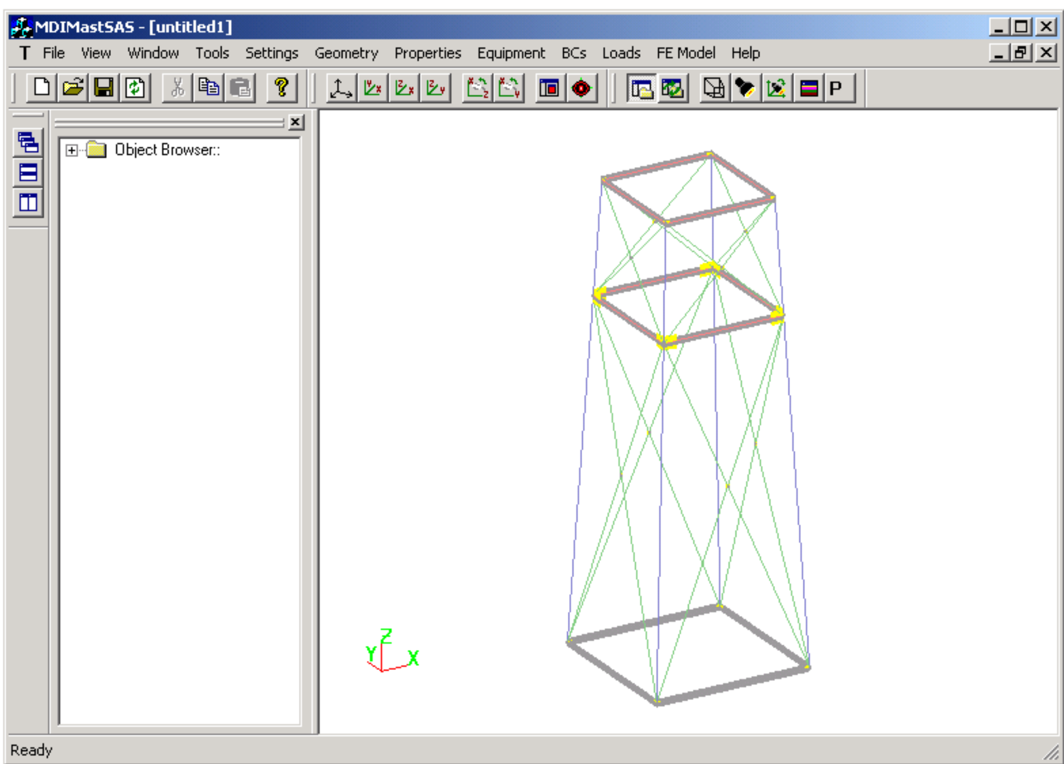



**Figure 2.8: Resulting main mast section (simple lattice mast)**

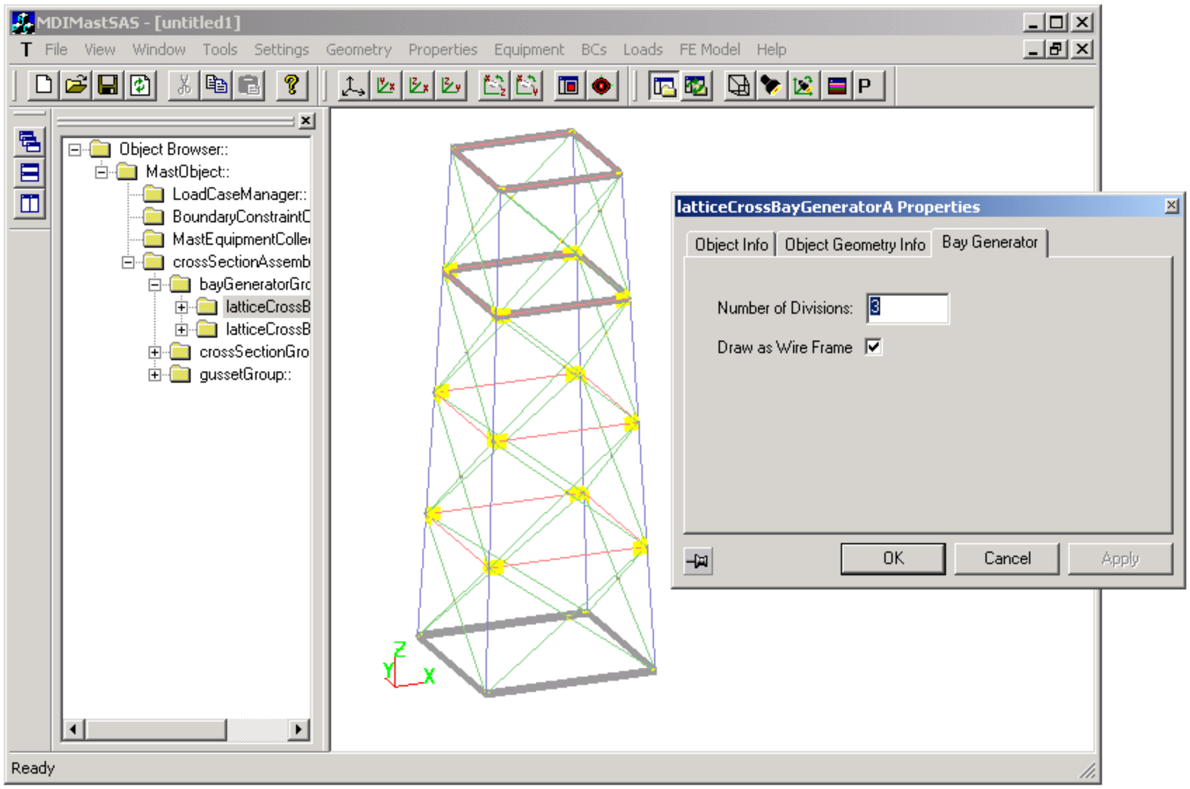



**Figure 2.9: Subdivision of lower bay of main mast section (simple lattice mast)**

### 2.2.2 Creating and Attaching Yardarms

A single yardarm will be created and attached using the following criteria:

- the yardarm (4-sided) is 3m in length
- the single bay of the yardarm will be attached to the starboard side of the topmost bay of the main mast structure
- inner-most (i.e., base) cross section measures 2.5m x 2.5m
- outer-most (i.e., top) cross section measures 2.5m x 1.5m
- lattice type ‘A’ is applied between yardarm cross sections
- main mast members are constructed of circular steel sections, with an inner and outer radii of 75mm and 125mm, respectively

The creation and attachment of the yardarm is described in Figure 2.10 through Figure 2.16 below.

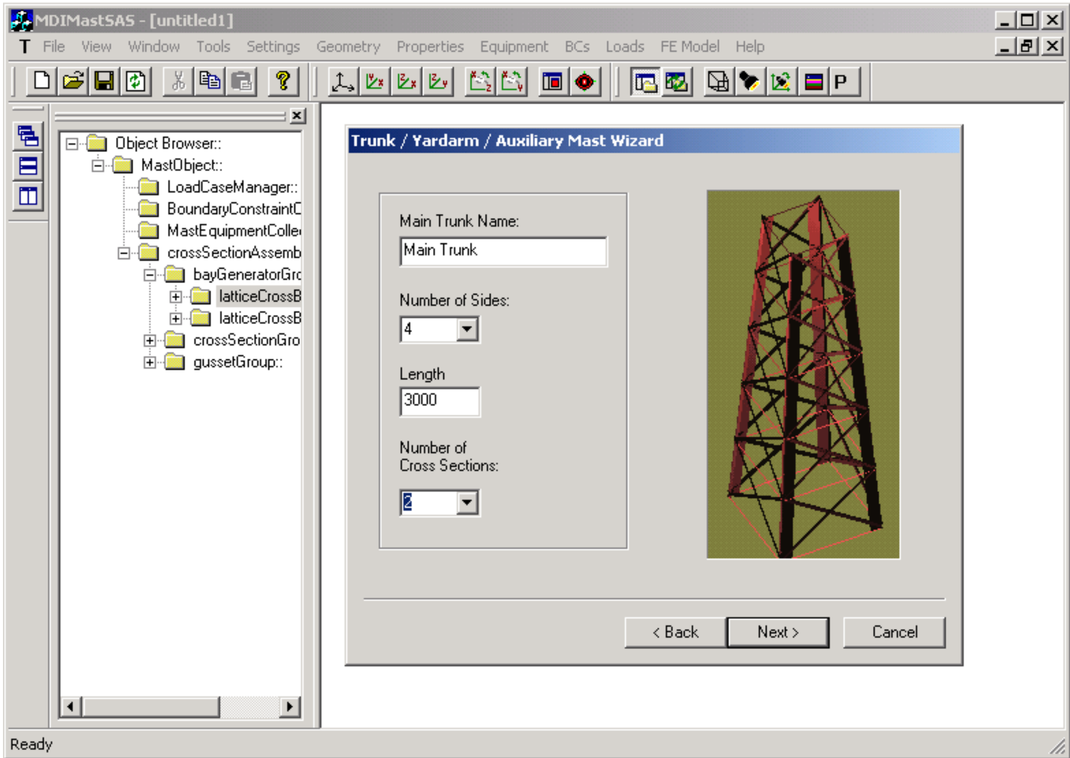



**Figure 2.10: Creating the main mast yardarm (simple lattice mast)**

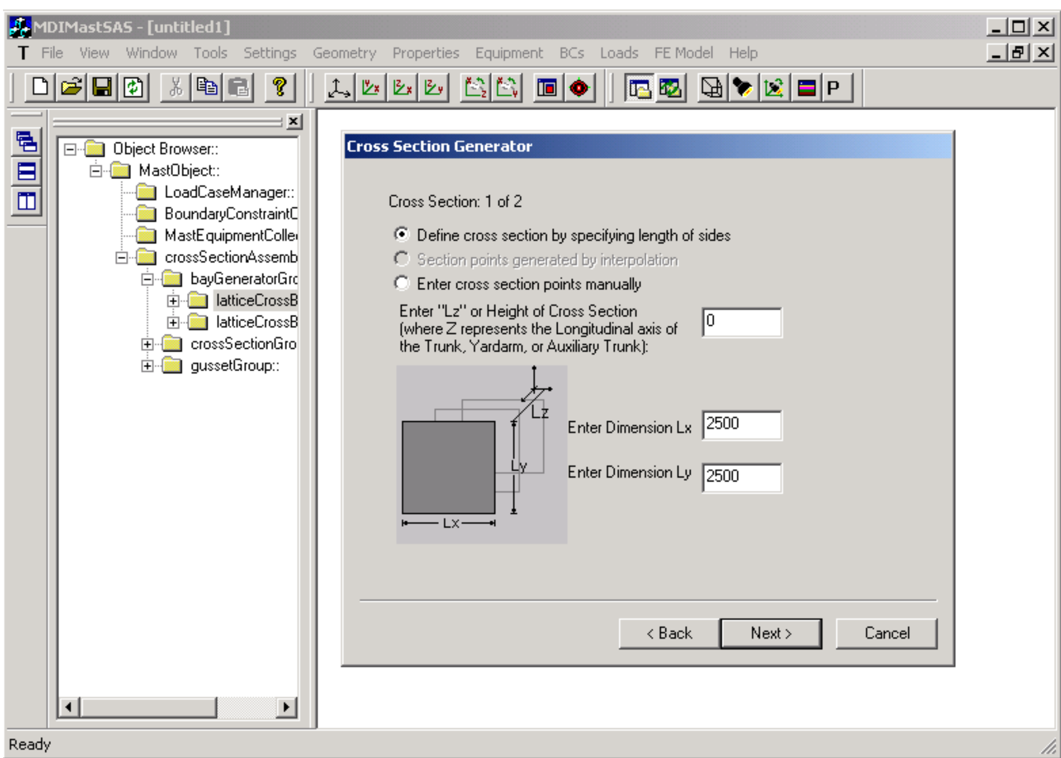



**Figure 2.11: Defining cross section (1 of 2) information for yardarm section**

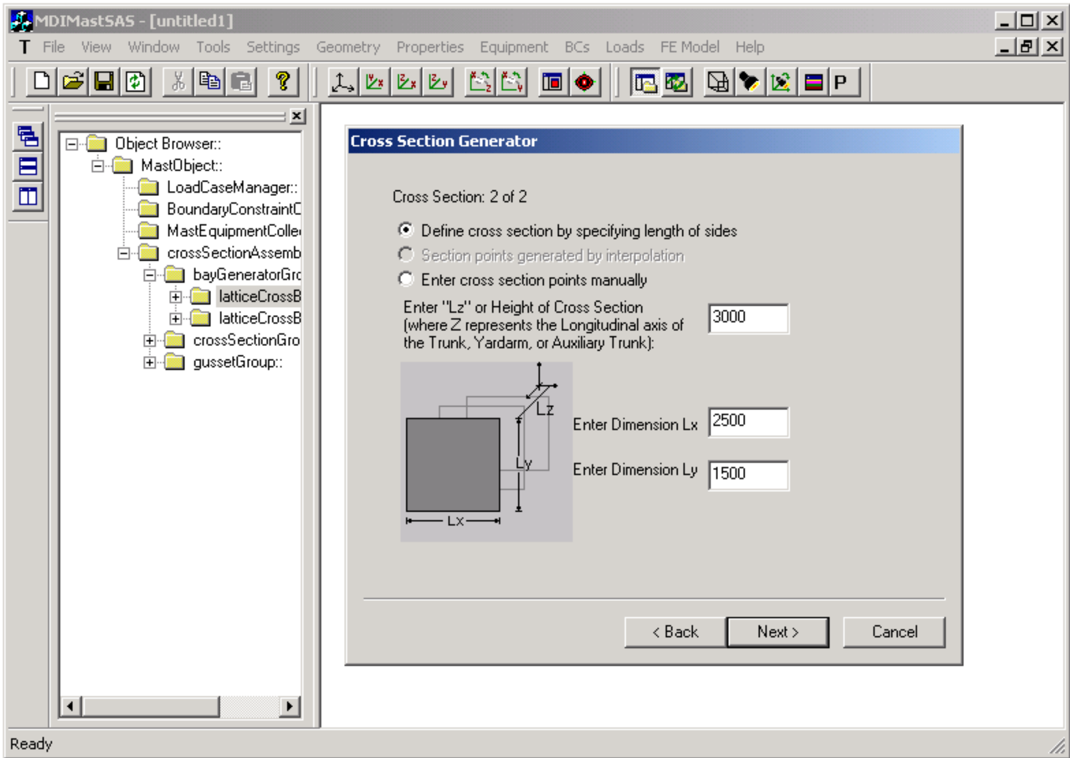



**Figure 2.12: Defining cross section (2 of 2) information for yardarm section**

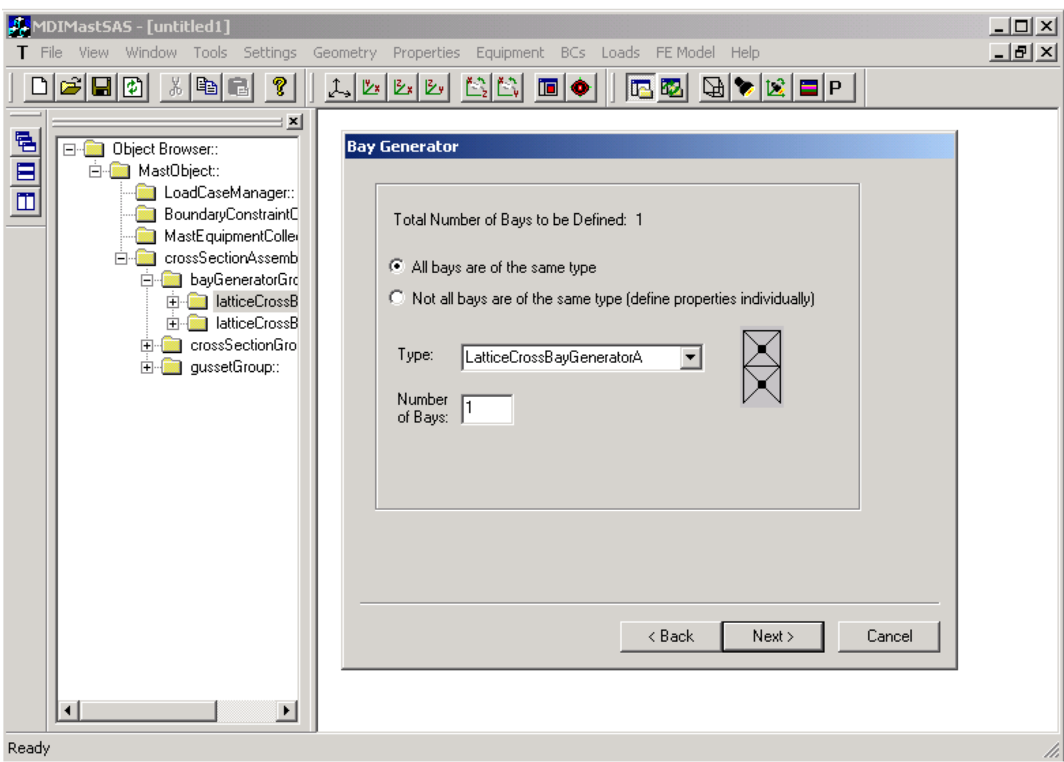



**Figure 2.13: Bay generation for yardarm section (simple lattice mast)**

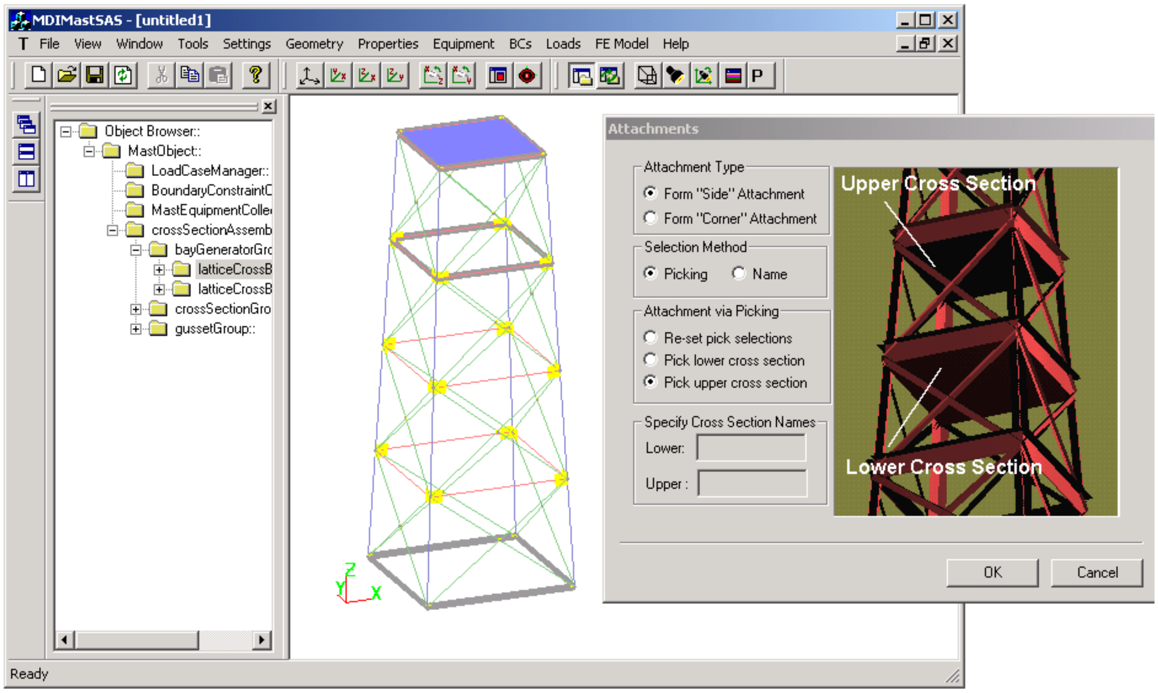



**Figure 2.14: Definition of upper cross section for yardarm connection to main mast**

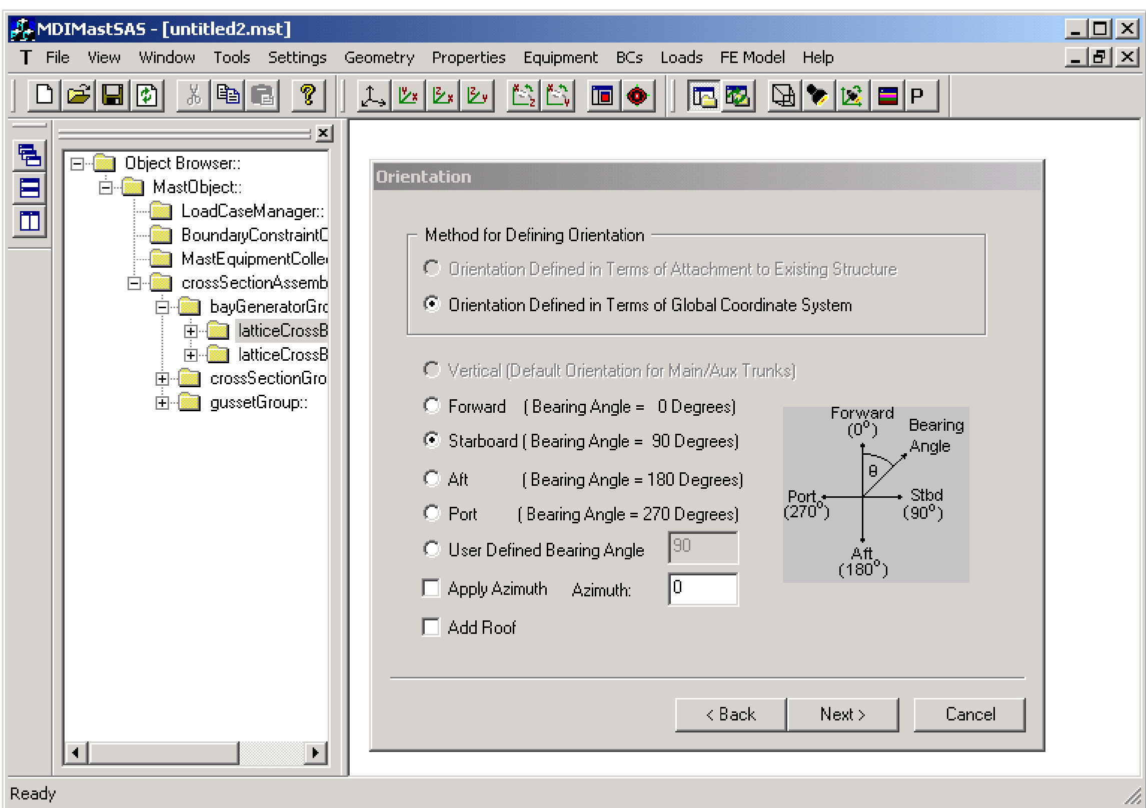



**Figure 2.15: Defining orientation of mast yardarm (simple lattice mast)**

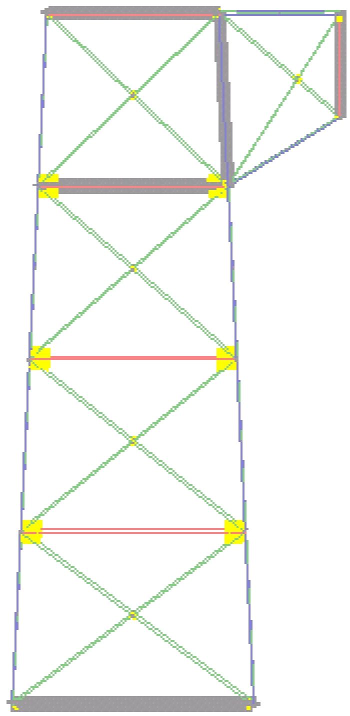


**Figure 2.16: Resulting structure, with main mast and yardarm (simple lattice mast)**

### 2.2.3 Creating and Attaching Auxiliary Masts

An auxiliary mast will be constructed atop the previously generated yardarm. The criteria governing its construction include:

- auxiliary mast (4-sided) is 6m in height and oriented vertically
- auxiliary mast consists of 3 evenly spaced cross sections, all measuring 2.5m square
- lattice type ‘A’ is applied between all cross sections
- auxiliary mast members are constructed of circular steel sections, with an inner and outer radii of 75mm and 125mm, respectively
- upper and lower bays are both subdivided to give four new bays of equal height
- the attachment location for the auxiliary mast is defined using the inner- and outer-most yardarm cross sections

Generation and attachment of the auxiliary mast is shown in the following figures.

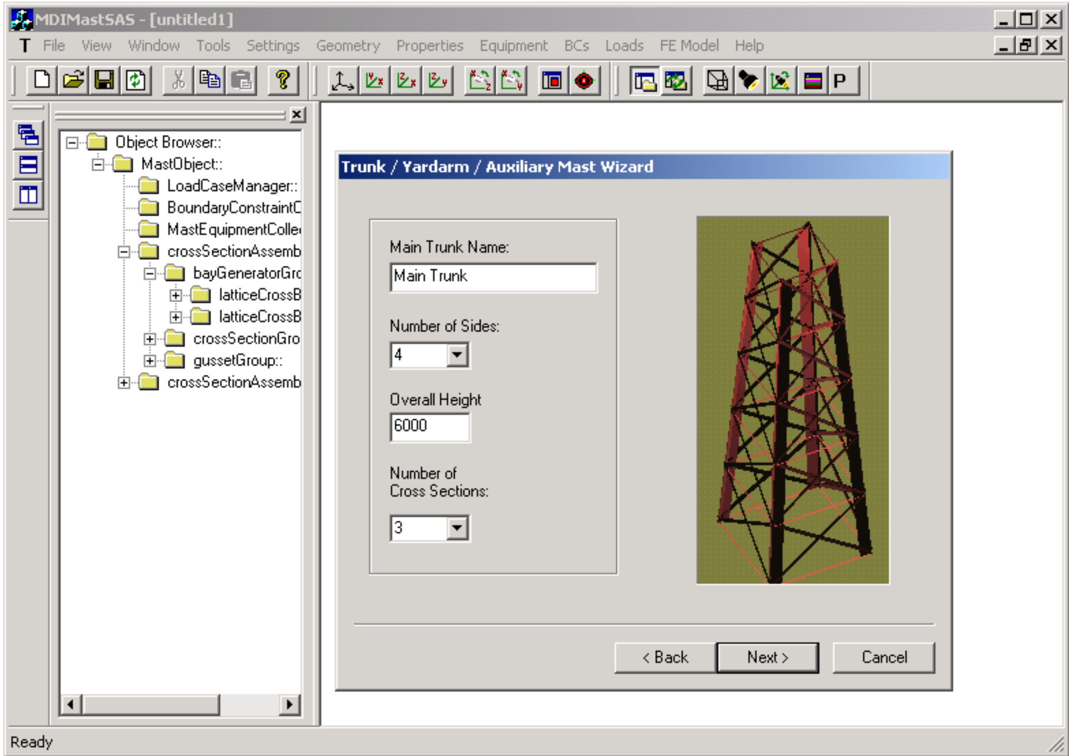



Figure 2.17: Creating an auxiliary mast structure (simple lattice mast)

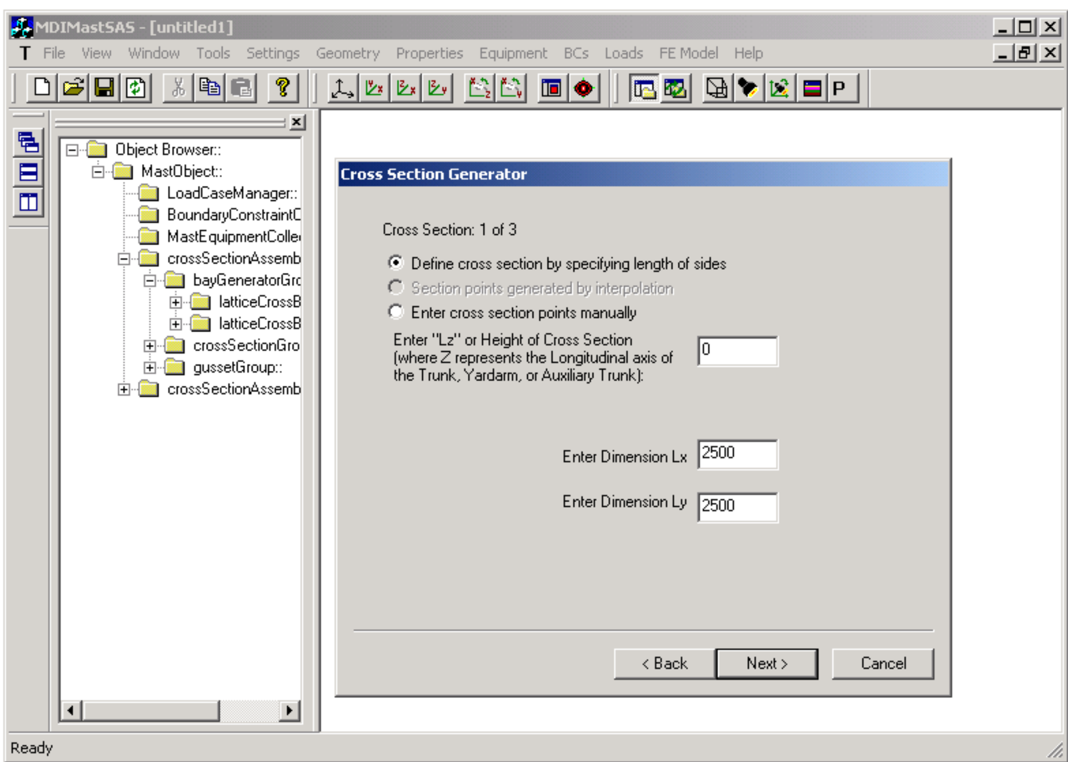



Figure 2.18: Defining cross section (2 of 3) information for auxiliary mast section

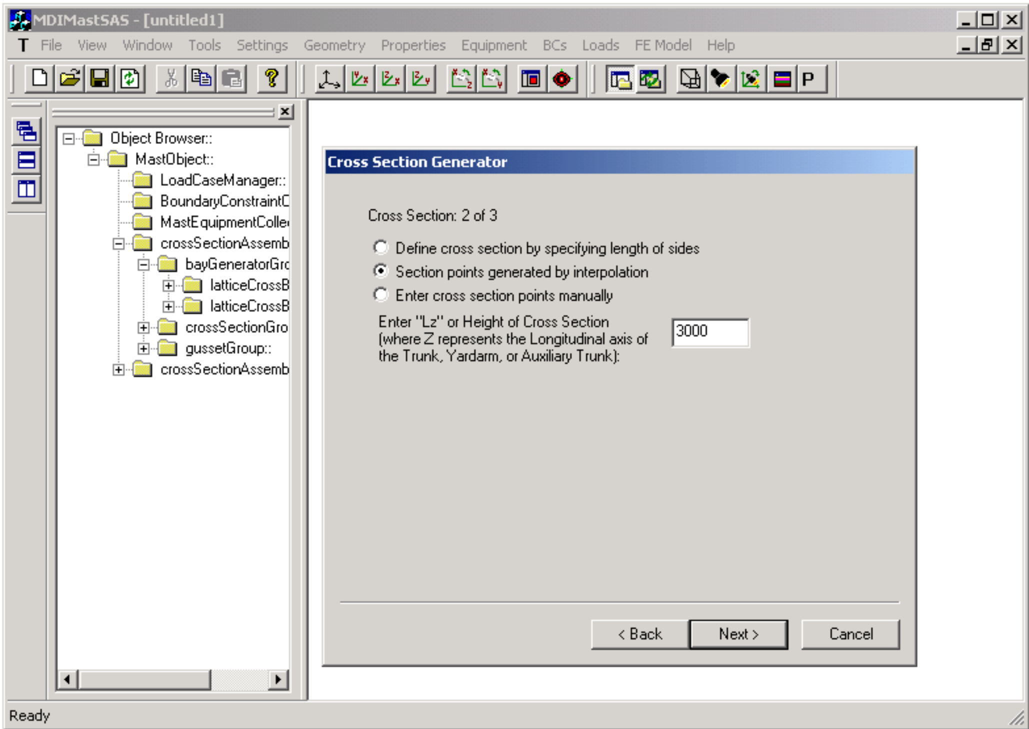



**Figure 2.19: Defining cross section (2 of 3) information for auxiliary mast section**

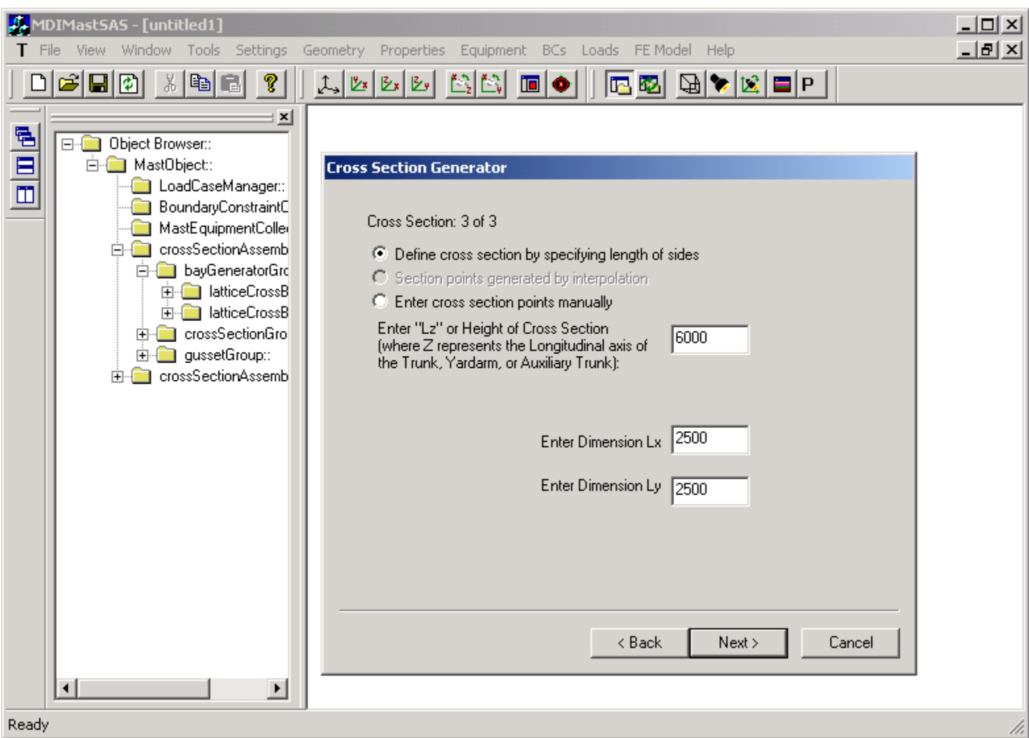



**Figure 2.20: Defining cross section (3 of 3) information for auxiliary mast section**

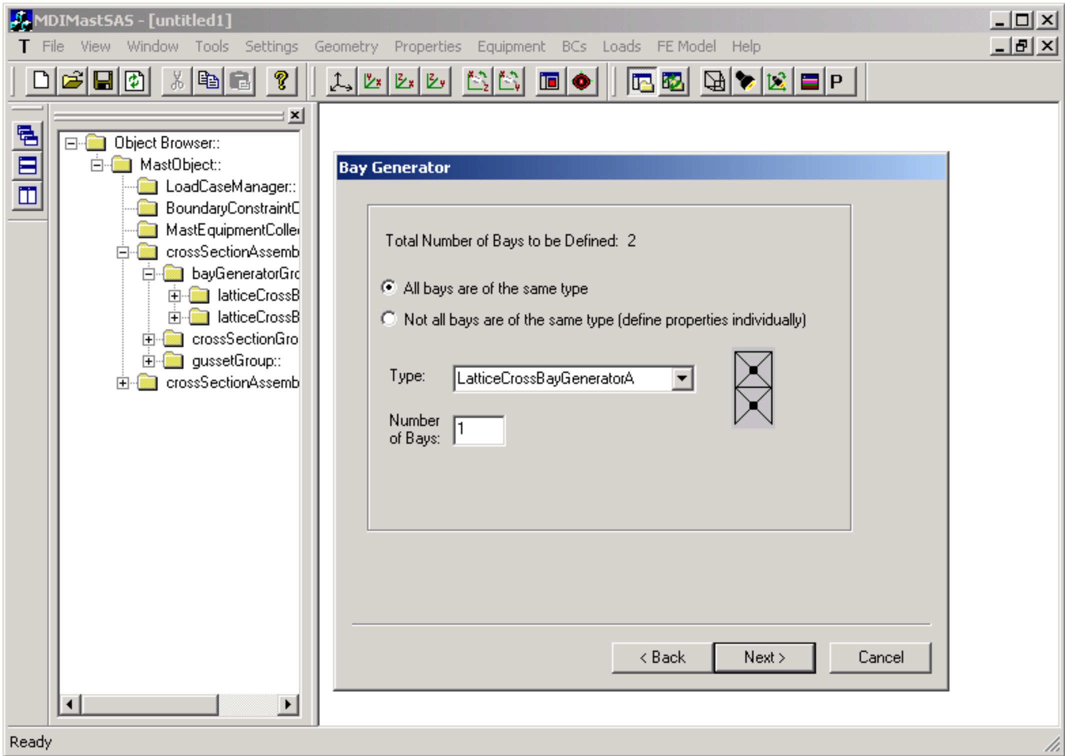



Figure 2.21: Bay generation for auxiliary mast section (simple lattice mast)

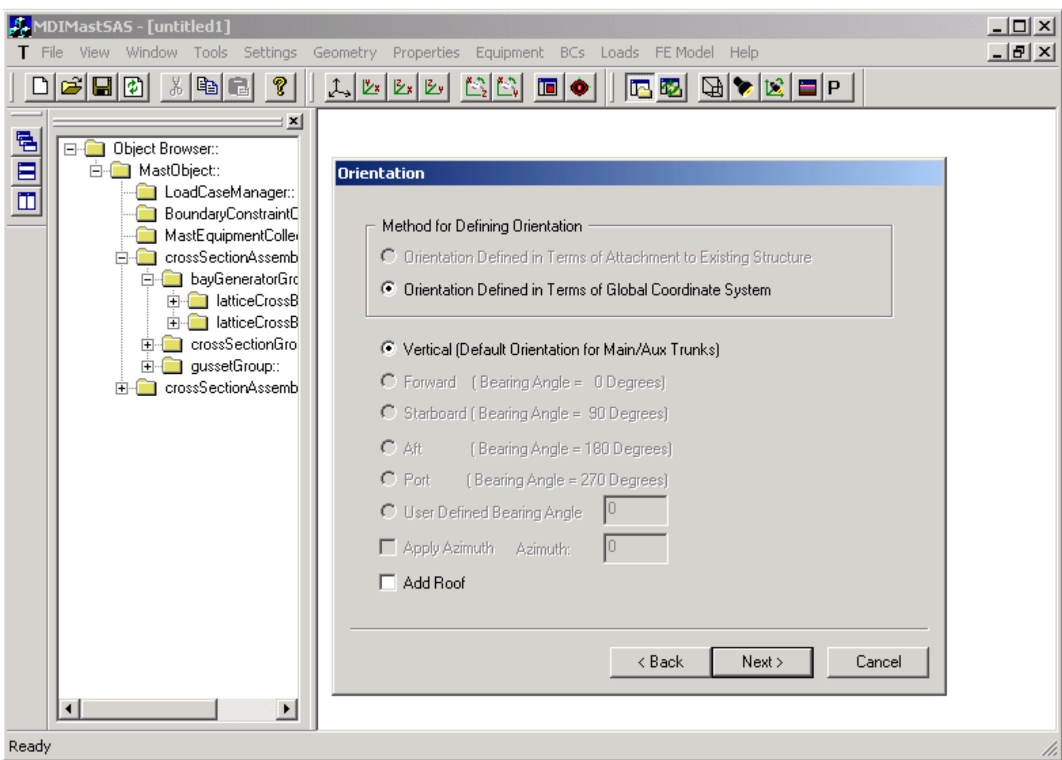



Figure 2.22: Defining orientation of auxiliary mast section (simple lattice mast)

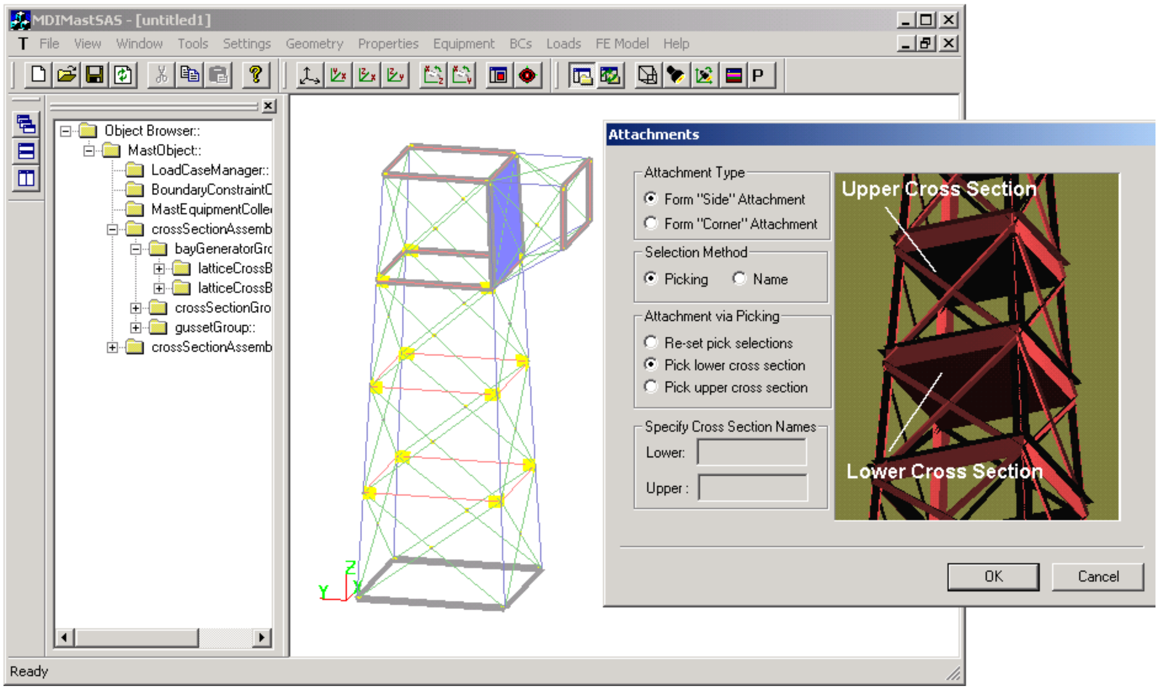



**Figure 2.23: Definition of lower (inner) cross section for auxiliary mast connection**

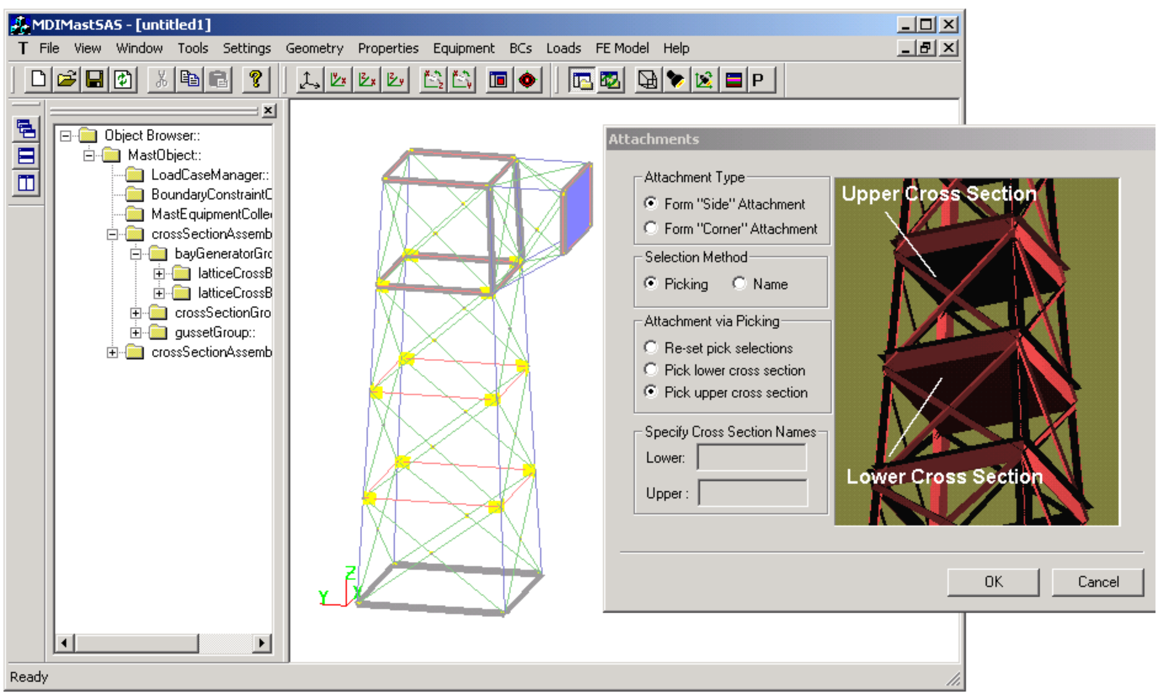



**Figure 2.24: Definition of upper (outer) cross section for auxiliary mast connection**

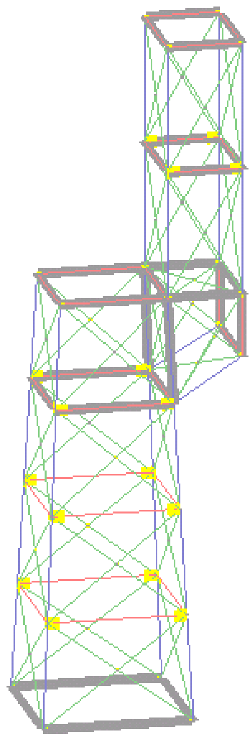


**Figure 2.25: Resulting mast showing main/auxiliary masts and yardarm (simple lattice mast)**

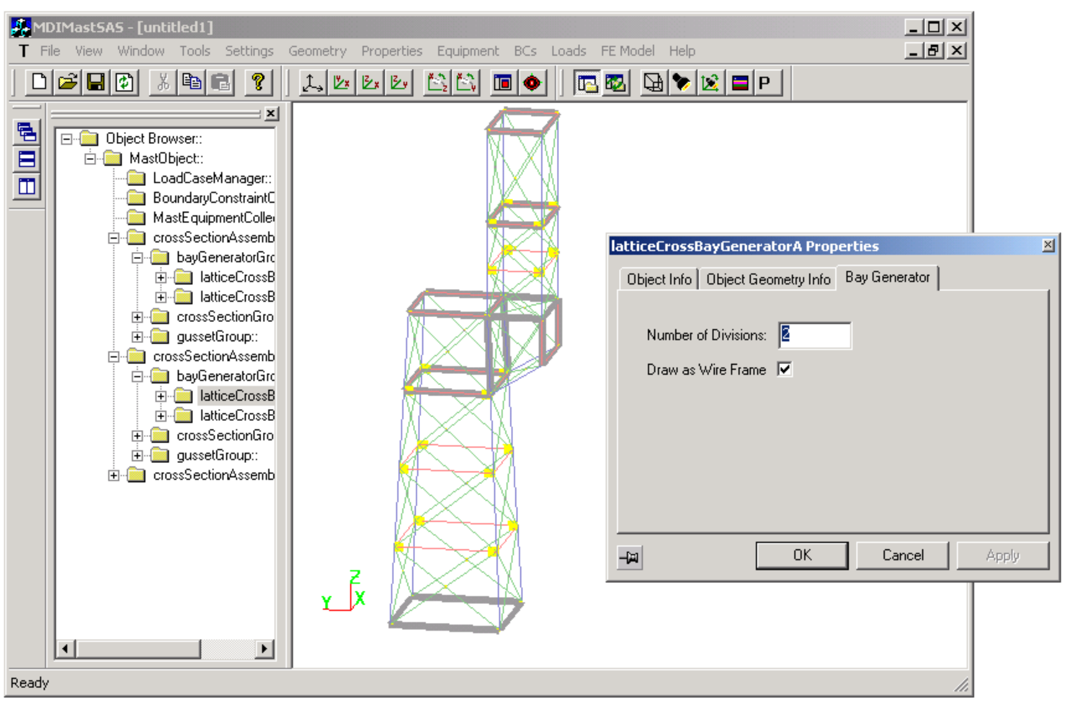



**Figure 2.26: Subdivision of lower bay of auxiliary mast**

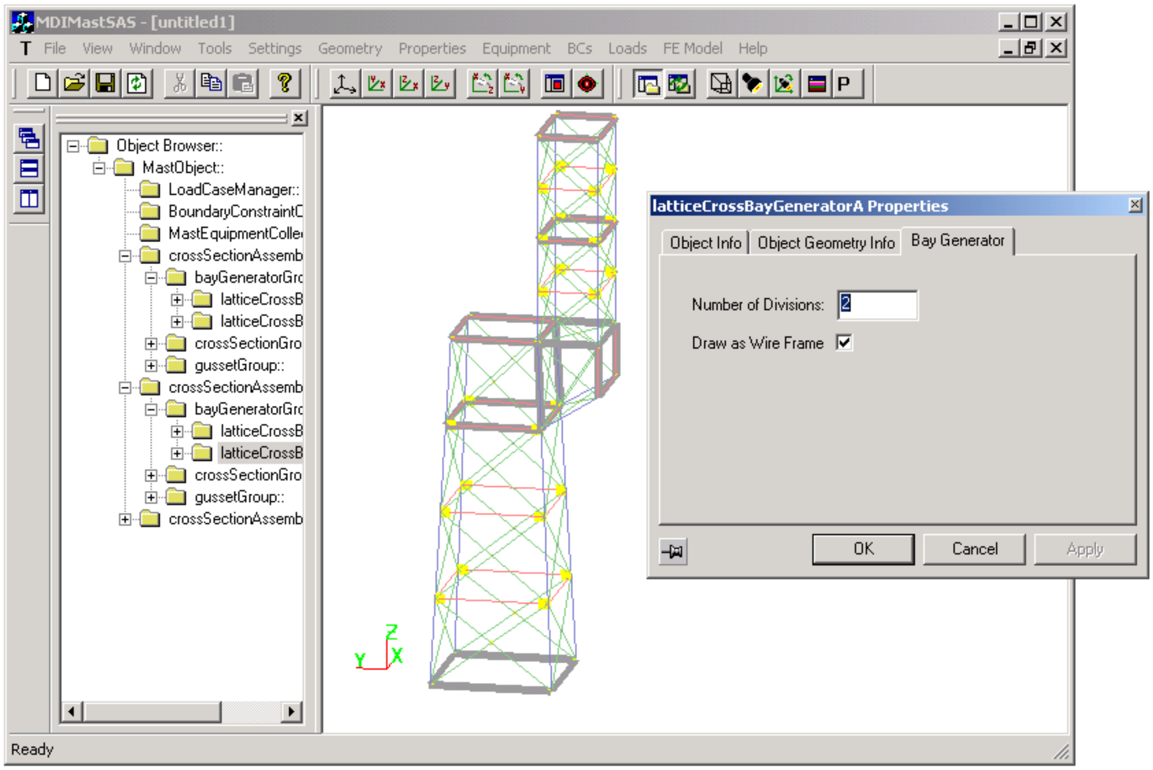



**Figure 2.27: Subdivision of upper bay of auxiliary mast**

### 2.2.4 Attaching Equipment

The figures below illustrate the generation of equipment and its attachment to the mast structure. The governing criteria include:

- equipment consists of a AN/SPS-12 cylindrical radar model weighing 450kg
- the equipment is attached to the starboard side of the auxiliary mast, at the forward corner, using offsets of 1m in the x, y, and z directions

In order to attach equipment, users must first display the *MastEquipmentCollector* property page (see Figure 2.28) by selecting the '*Modify*' option listed under the main menu's *Equipment* tab. Next, using the *MastEquipmentCollector* property page, a new equipment object can be created by selecting the *New* button. Doing so will display the property page for the new equipment object (see Figure 2.29). Users can then define the equipment type (MASTSAS provides a database of various equipment types – see Figure 2.30), the orientation, attachment location, and offsets for the new equipment object (see Figure 2.31). Once the definition is complete, the *MastEquipmentCollector* is updated, providing a summary of the attributes for the new equipment object (see Figure 2.32).

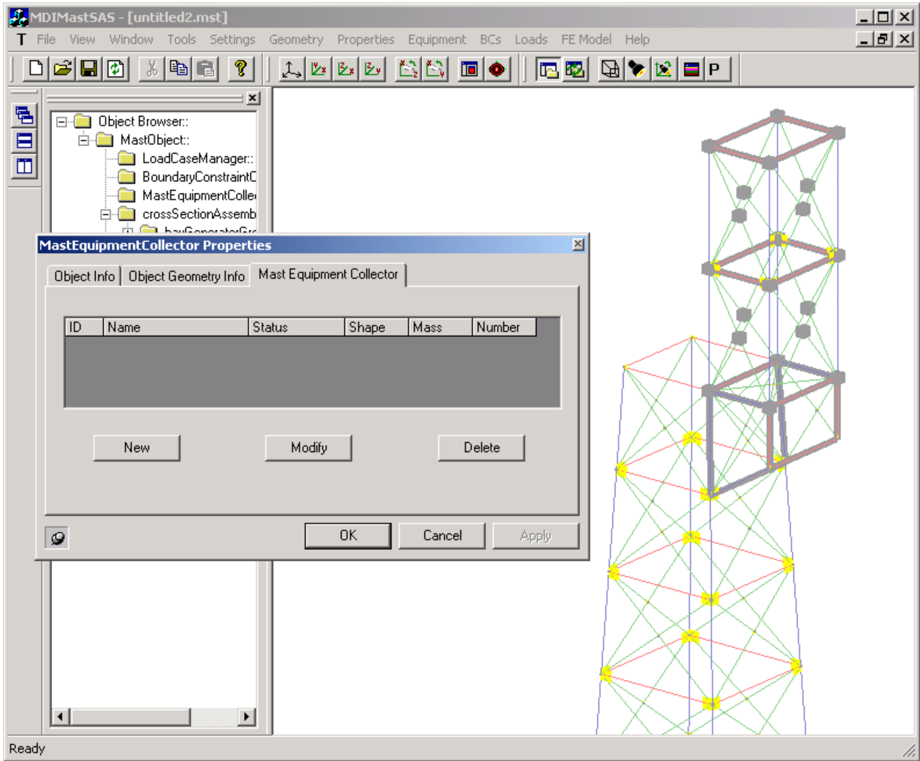



Figure 2.28: *MastEquipmentCollector* property page

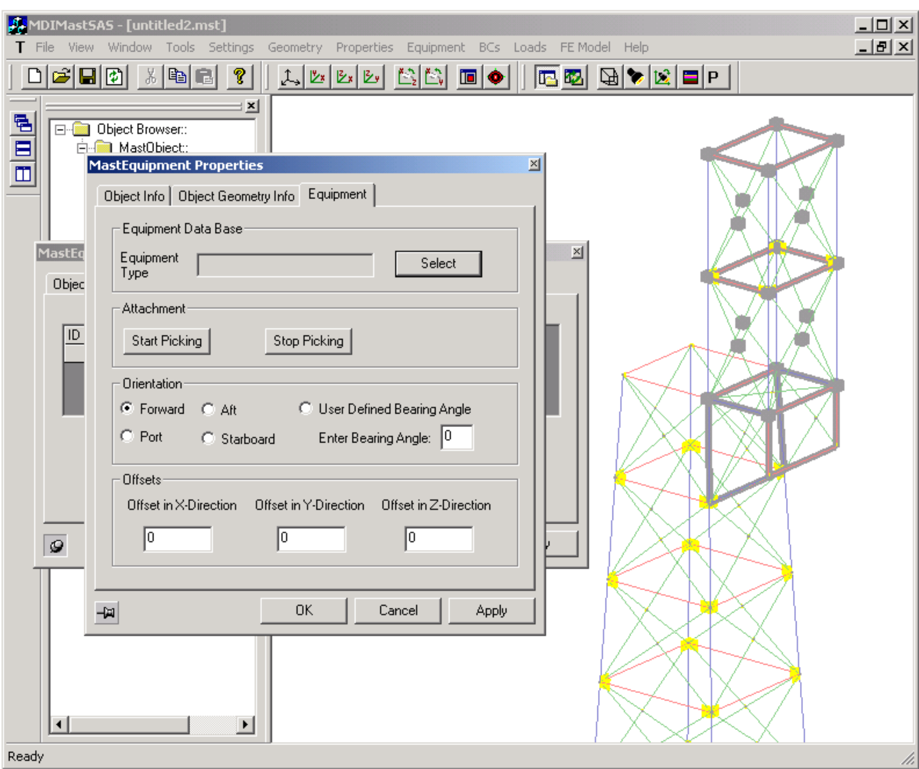



Figure 2.29: *MastEquipmentObject* property page

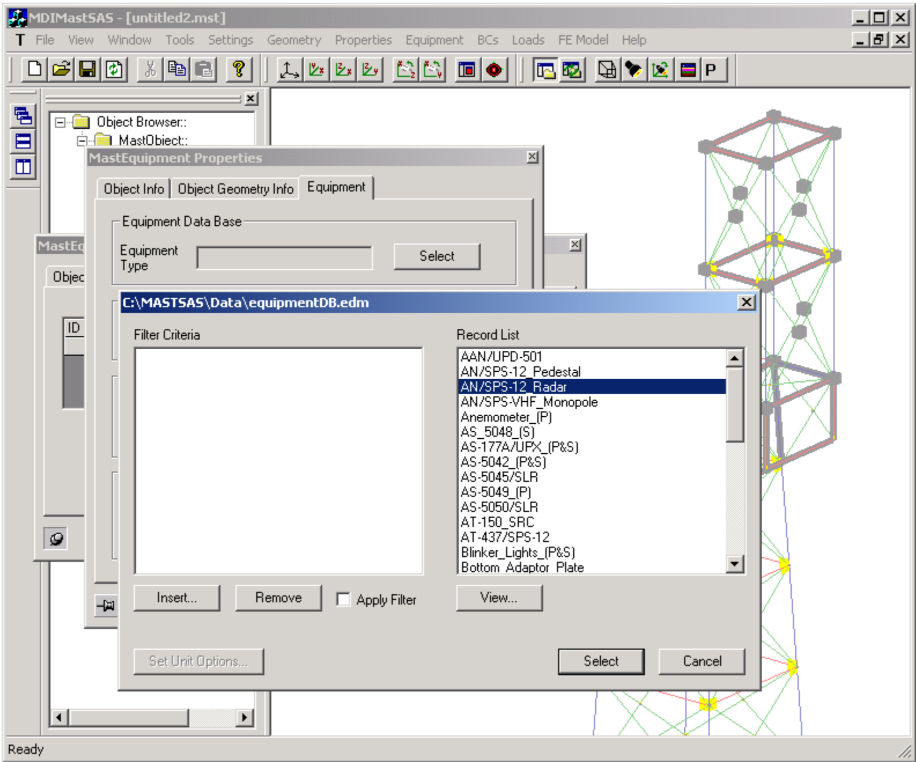



**Figure 2.30: Selection of mast equipment from database**

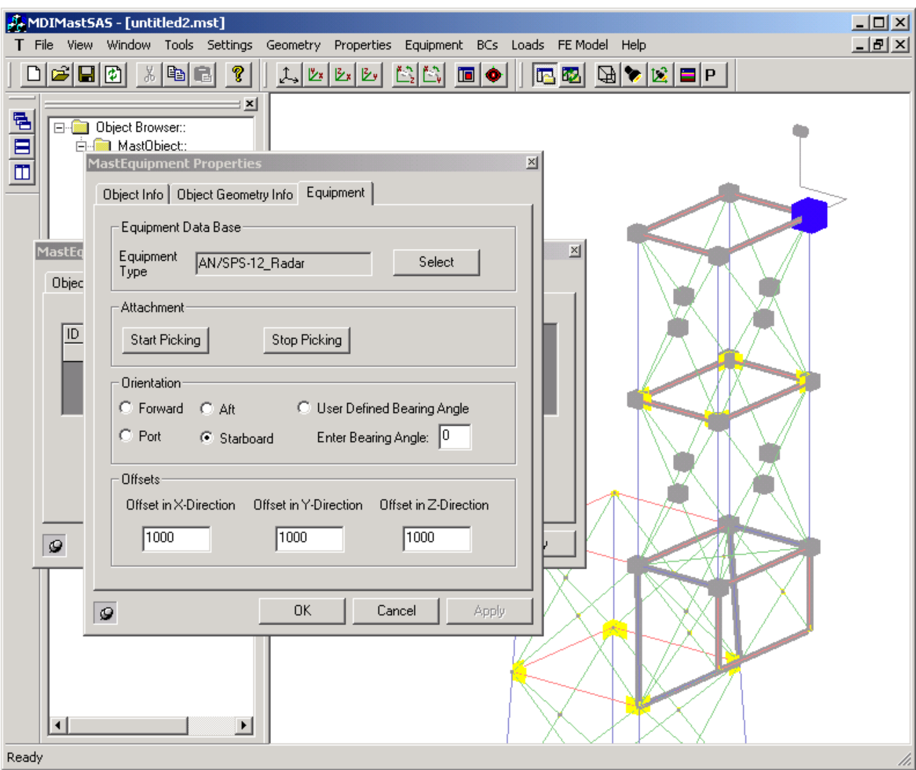



**Figure 2.31: New equipment attributes supplied by user**

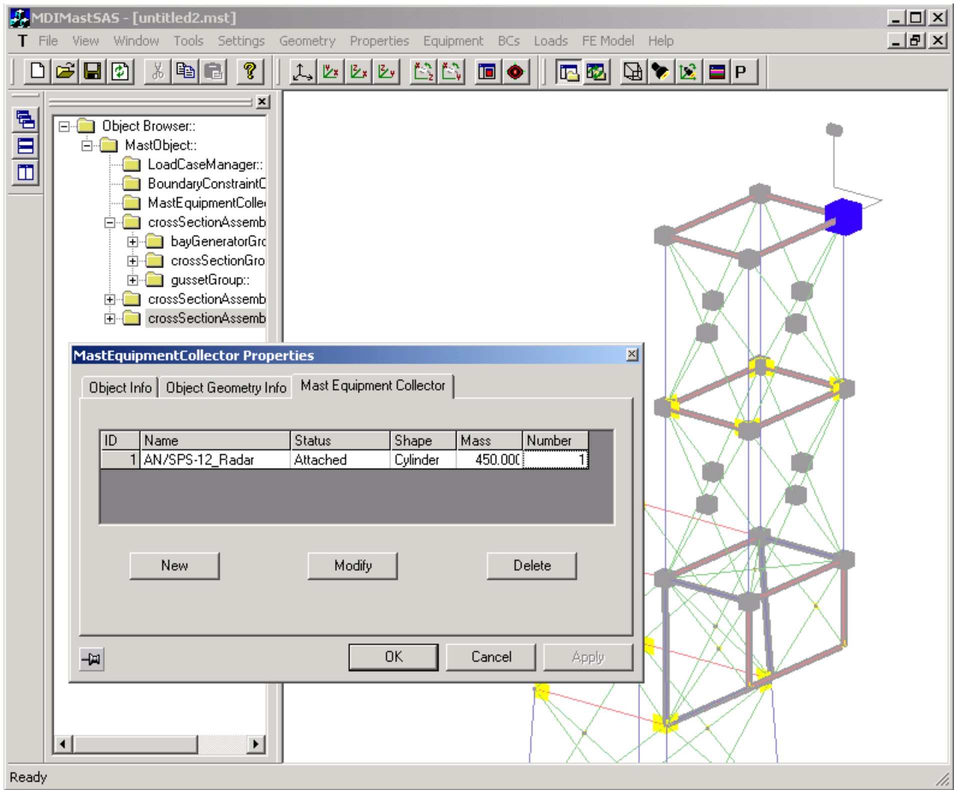


**Figure 2.32: Summary of mast equipment attributes**

## 2.3 Application of Boundary Conditions

The mast structure will be restrained using fixed boundary conditions, applied to the nodes defining the base cross section. Application of these boundary conditions is shown in the figures below.

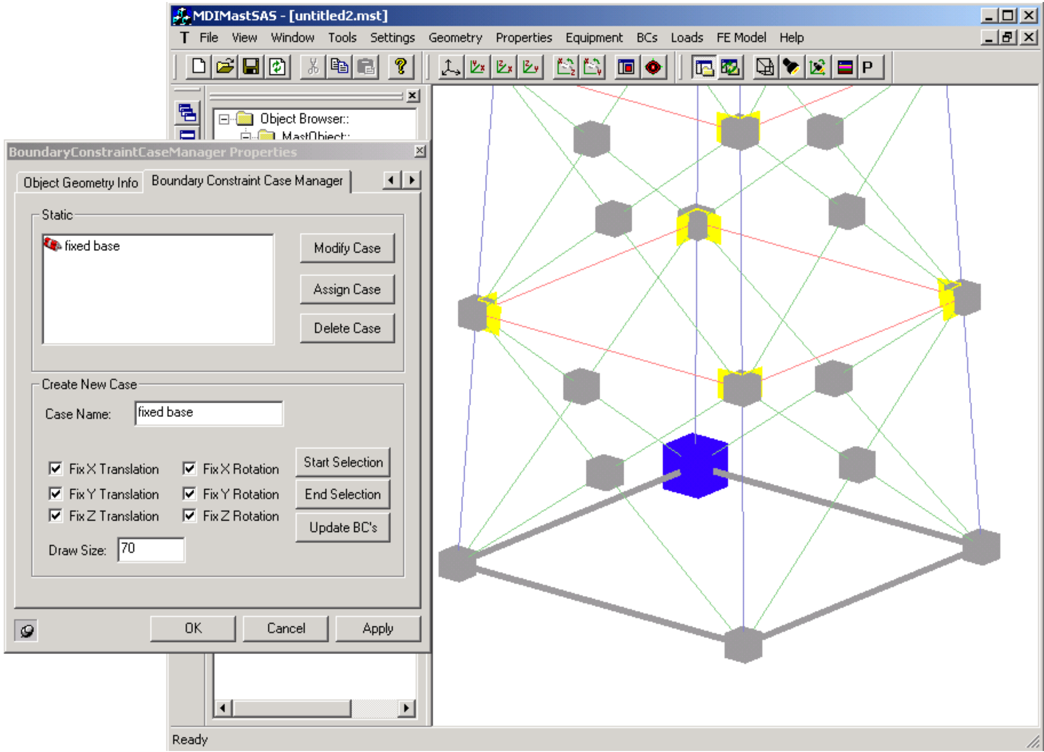



**Figure 2.33: Nodal identification for application of boundary conditions**

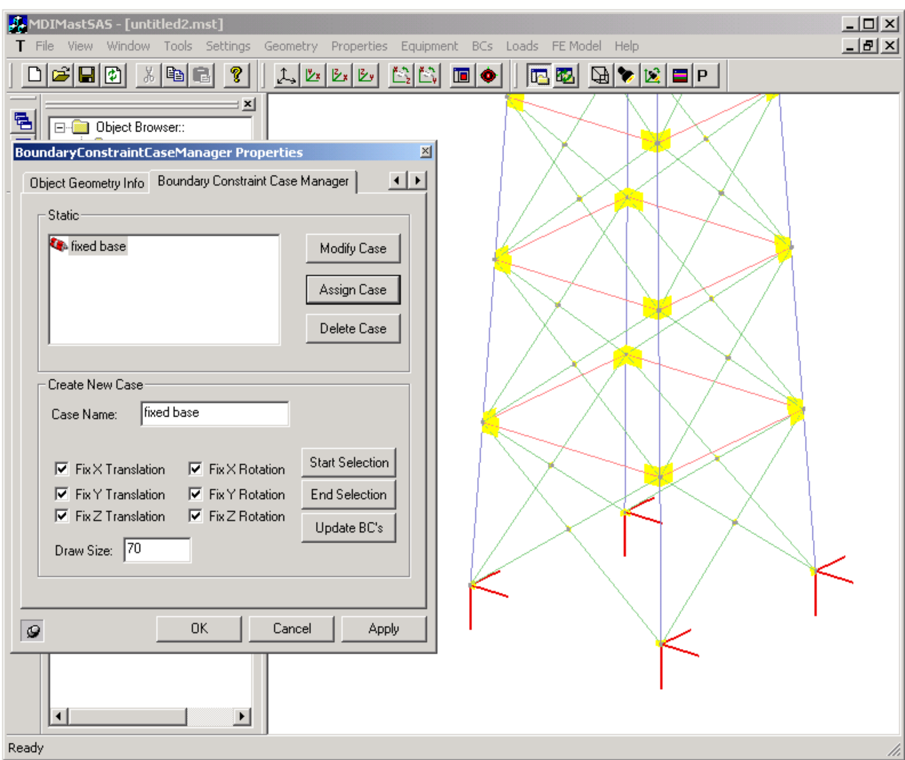



**Figure 2.34: Specification of boundary conditions for base cross section (simple lattice mast)**

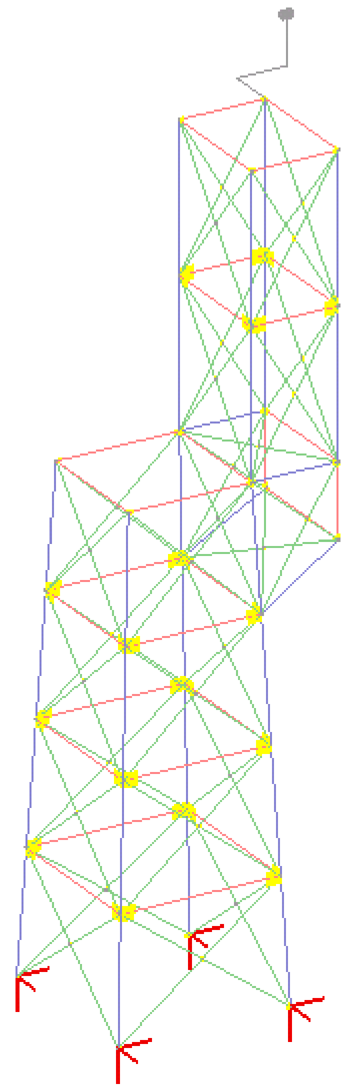


**Figure 2.35: Simple lattice mast, showing geometric connections, attached equipment, and applied boundary conditions**

## 2.4 Generation and Application of Loads

In this first example, only those loads imposed due to structural self-weight will be included. Application of structural self-weight is accomplished by:

- assigning a 'new' load case, and
- selecting 'Self Weight' from the options available

Load generation and application for the simple lattice mast are described in the figures below.

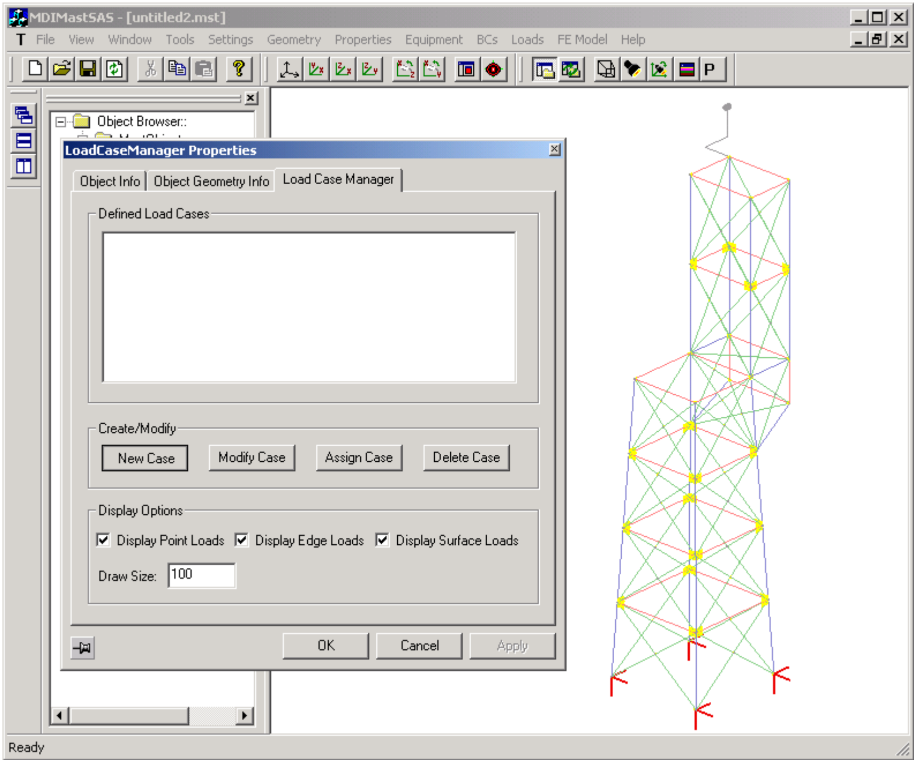



**Figure 2.36: Specification of new load case**

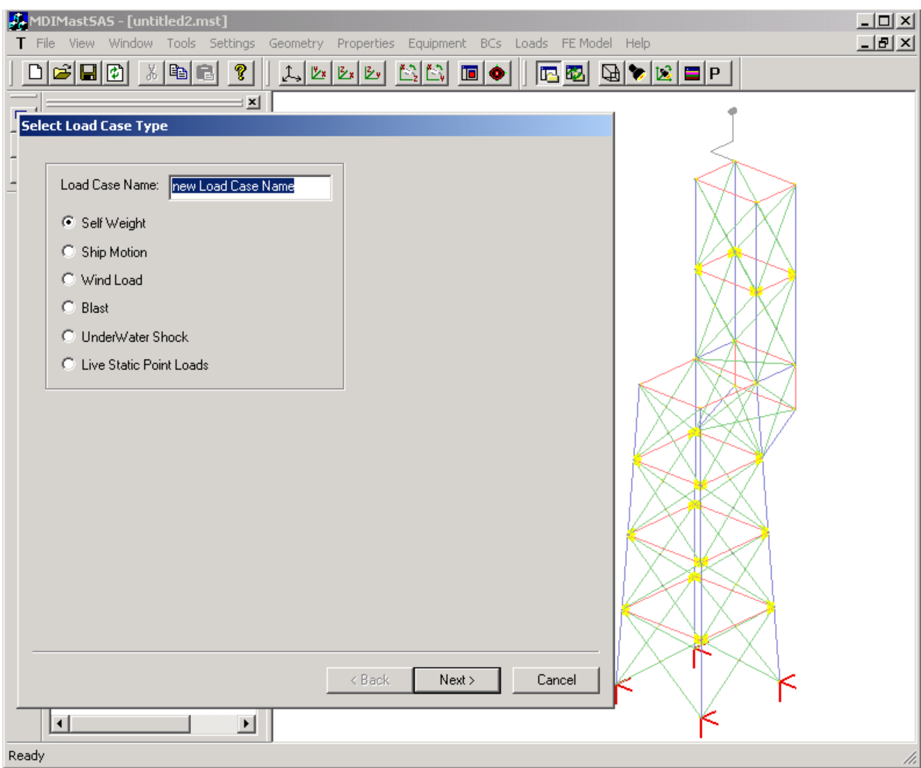



**Figure 2.37: Load case definition (simple lattice mast)**

## 2.5 Finite Element Modeling

A finite element model of the mast structure can be generated using MASTSAS' '*Boundary FE Detail*' features. The following guidelines may be used to produce a suitable mesh and prepare an appropriate input file for the DSA/VAST solver:

- set the 'Create Mesh Flag' and select the 'Hidden Line Mesh' option from the display mode features
- export the model mesh to a DSA database format

MASTSAS' finite element modeling procedures are described in the figures below.

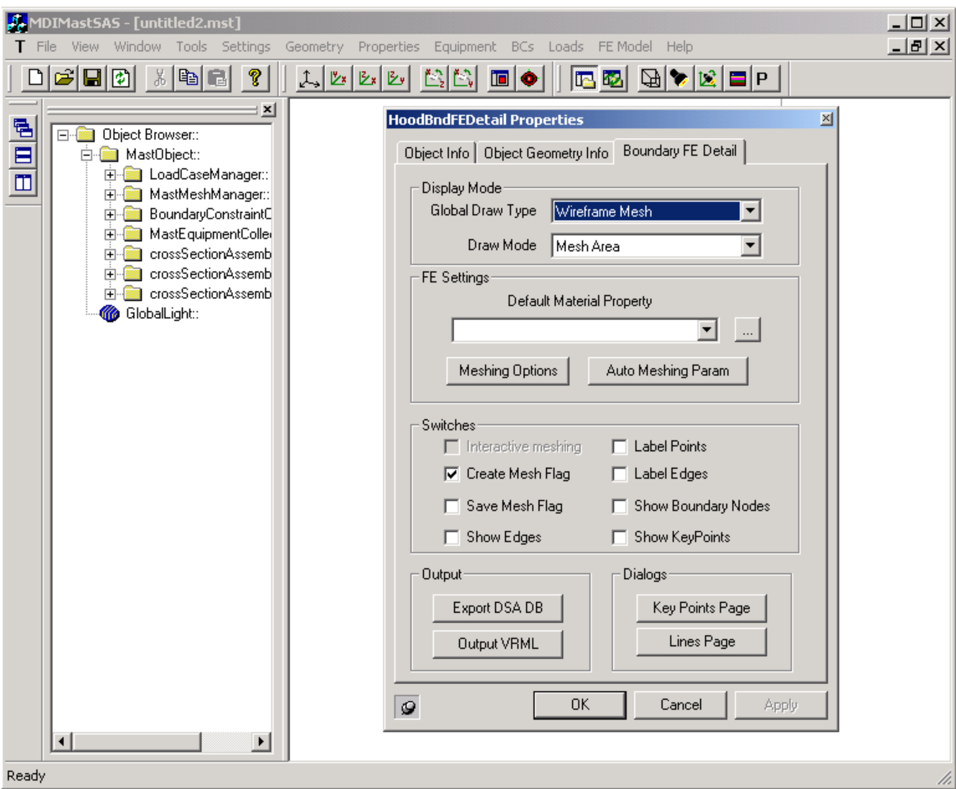



**Figure 2.38: Specification of finite element meshing details (simple lattice mast)**

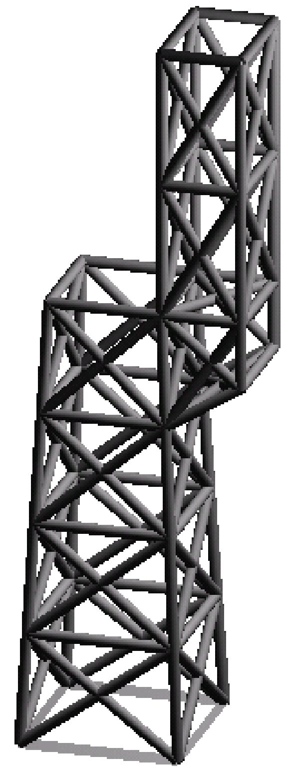


**Figure 2.39: Finite element model of lattice mast geometry (simple lattice mast)**

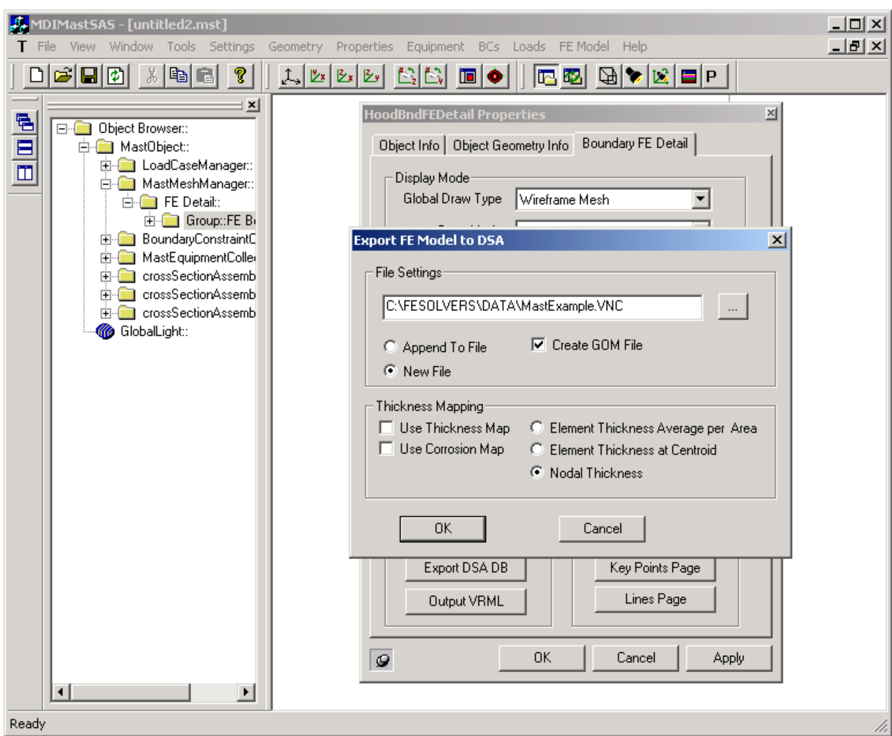



**Figure 2.40: Generation of DSA database file (simple lattice mast)**

## 2.6 Analysis

Analysis results for the simple lattice mast are illustrated in the figures below. It is seen that the fundamental natural frequency of the lattice mast structure is 1.362 Hz.

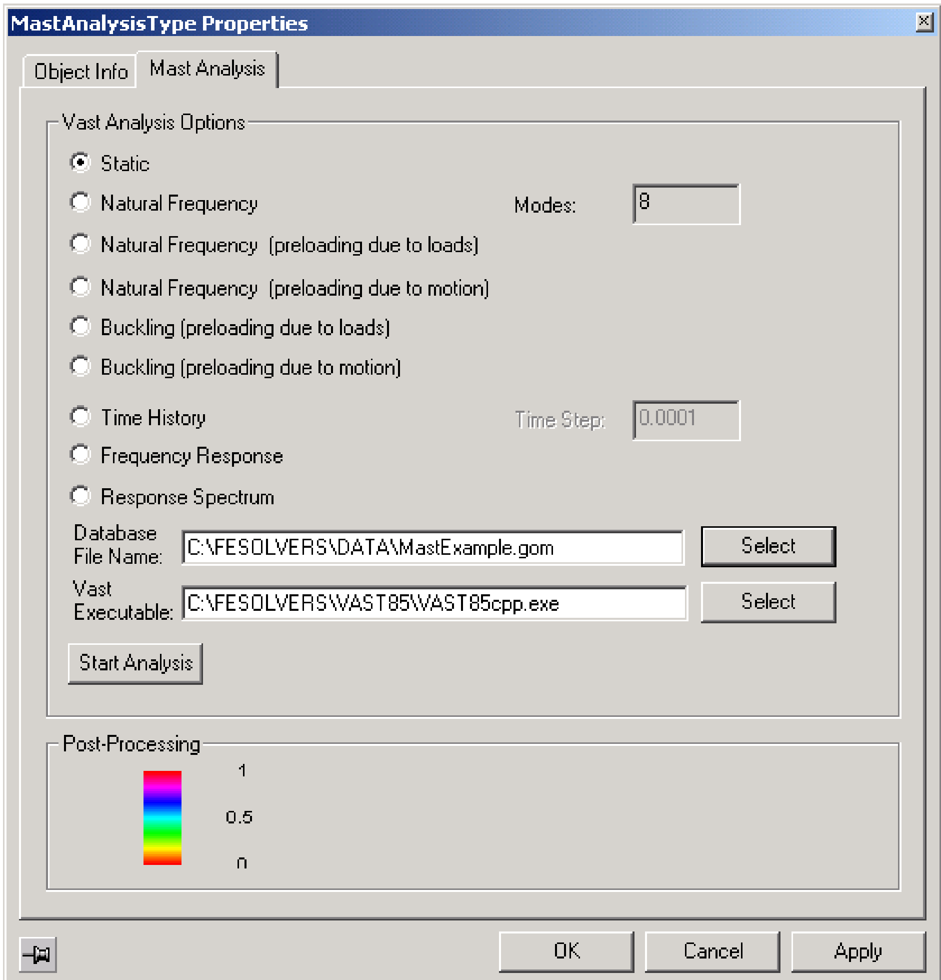



**Figure 2.41: Launching of MASTSAS analysis**

```
NATURAL FREQUENCY #    1  (C.P.S.) =  0.13620E+01    NUMBER OF ITERATIONS =  15
NATURAL FREQUENCY #    2  (C.P.S.) =  0.14721E+01    NUMBER OF ITERATIONS =   3
NATURAL FREQUENCY #    3  (C.P.S.) =  0.84054E+01    NUMBER OF ITERATIONS =   5
NATURAL FREQUENCY #    4  (C.P.S.) =  0.15634E+02    NUMBER OF ITERATIONS =   6
NATURAL FREQUENCY #    5  (C.P.S.) =  0.20845E+02    NUMBER OF ITERATIONS =   3
NATURAL FREQUENCY #    6  (C.P.S.) =  0.24120E+02    NUMBER OF ITERATIONS =   3
NATURAL FREQUENCY #    7  (C.P.S.) =  0.34632E+02    NUMBER OF ITERATIONS =   3
NATURAL FREQUENCY #    8  (C.P.S.) =  0.37902E+02    NUMBER OF ITERATIONS =   4
```

**Figure 2.42: Results of MASTSAS natural frequency analysis (simple lattice mast)**

# 3. STATIC ANALYSIS OF A SIMPLE ENCLOSED STEEL MAST SUBJECTED TO ENVIRONMENTAL LOADING (EXAMPLE 2)

## 3.1 Problem Description

The second example problem presents a static analysis of a simple enclosed mast. Topics discussed include generation of mast geometry (including stiffened panels and cut-outs), material and property selection, application of boundary conditions and environmental loading, finite element model development, and preparing the analysis.

## 3.2 Geometry

### 3.2.1 Creating the Main Trunk

The main trunk of the enclosed mast structure will be generated based on the following requirements:

- main mast structure is hexagonal (6-sided), with an overall height of 10m (oriented vertically)
- structure consists of 3 identical cross sections, located at 0m, 5m, and 10m
- all cross sections are based on a characteristic side length of 2.5m
- enclosed bays are generated using stiffened panels between major cross sections
- the six sides of each enclosed bay are generated using three equally spaced horizontal stiffeners (with an ‘edge’ spacing of 0.5m) and three equally spaced vertical stiffeners (also with an ‘edge’ spacing of 0.5m)
- the panel plating is of 12.5mm thickness, while the panel stiffeners are constructed from 127x70 (mm) Tee sections
- both the plating and stiffeners are constructed from ordinary steel

Generation of the enclosed mast geometry is shown in Figure 3.1 through Figure 3.10 below.

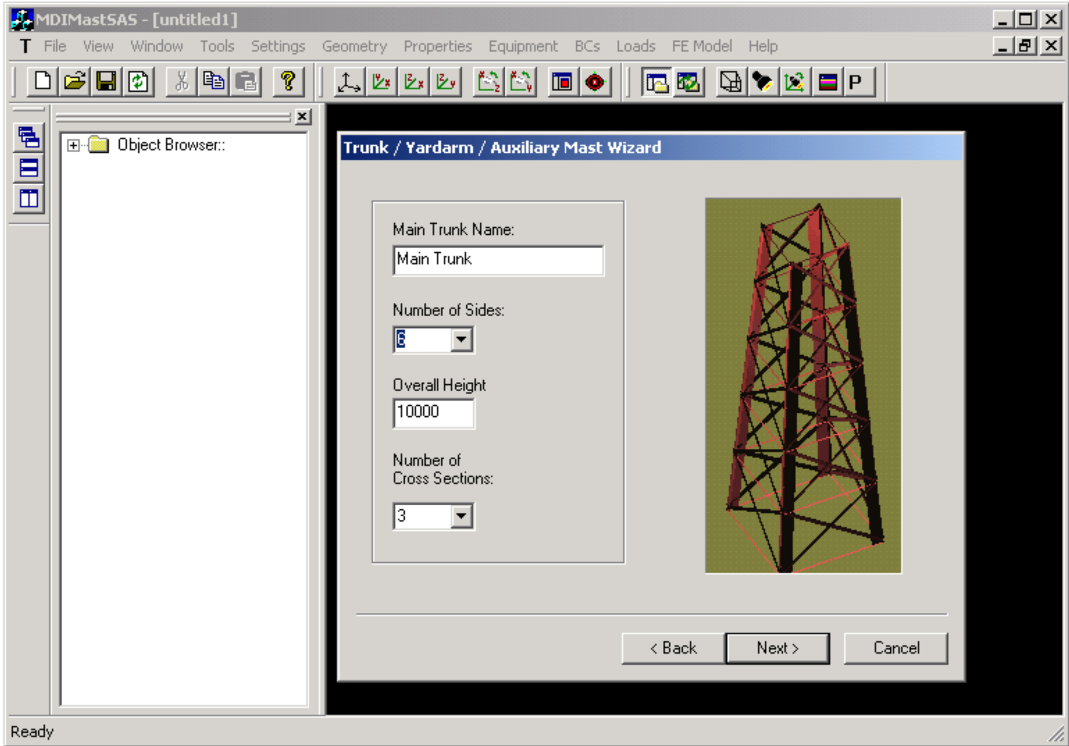



**Figure 3.1: Creating the main mast section (simple enclosed mast)**

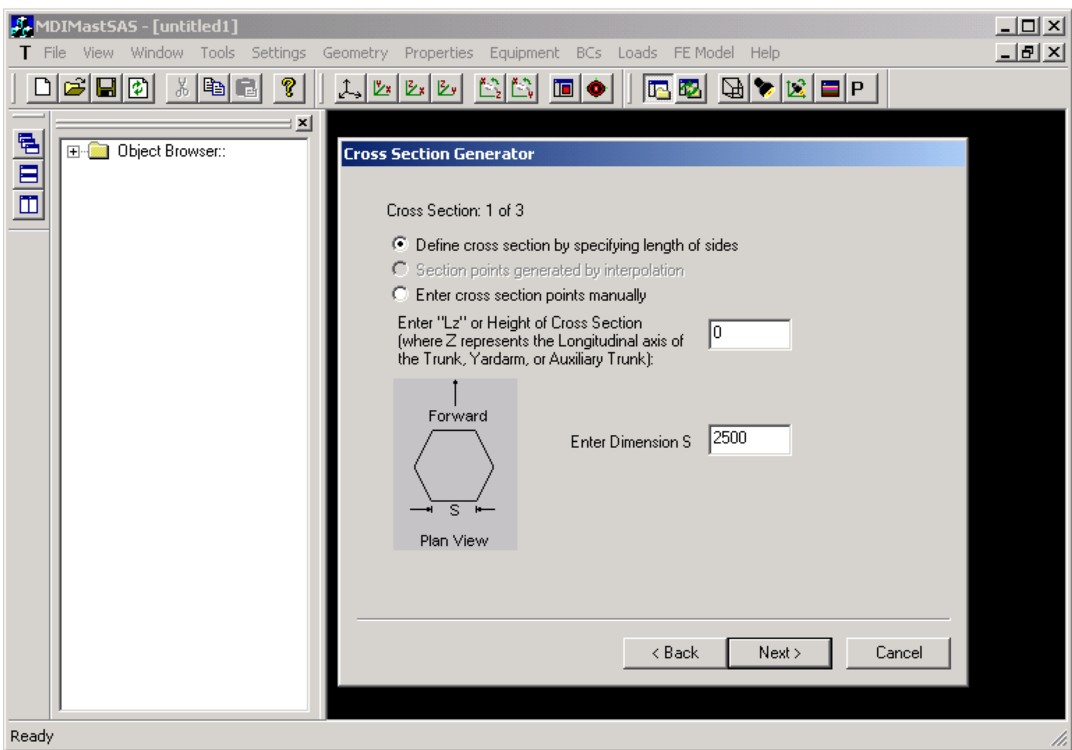



**Figure 3.2: Defining cross section (1 of 3) information for main mast section**

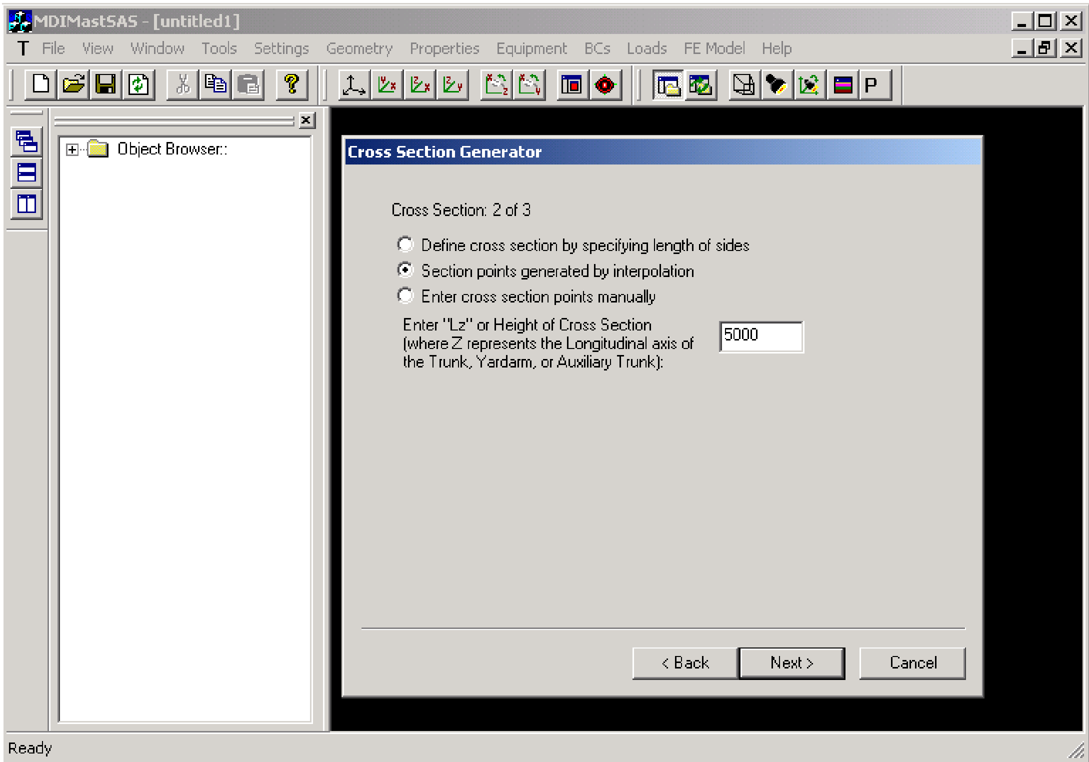



**Figure 3.3: Defining cross section (2 of 3) information for main mast section**

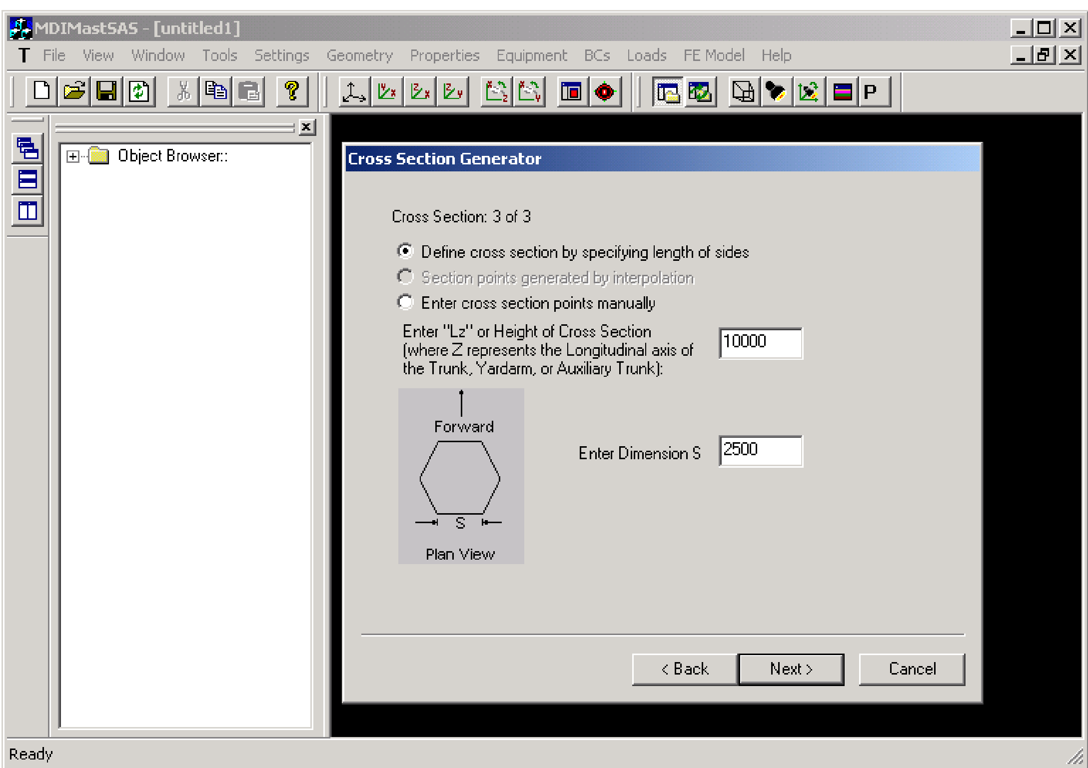



**Figure 3.4: Defining cross section (3 of 3) information for main mast section**

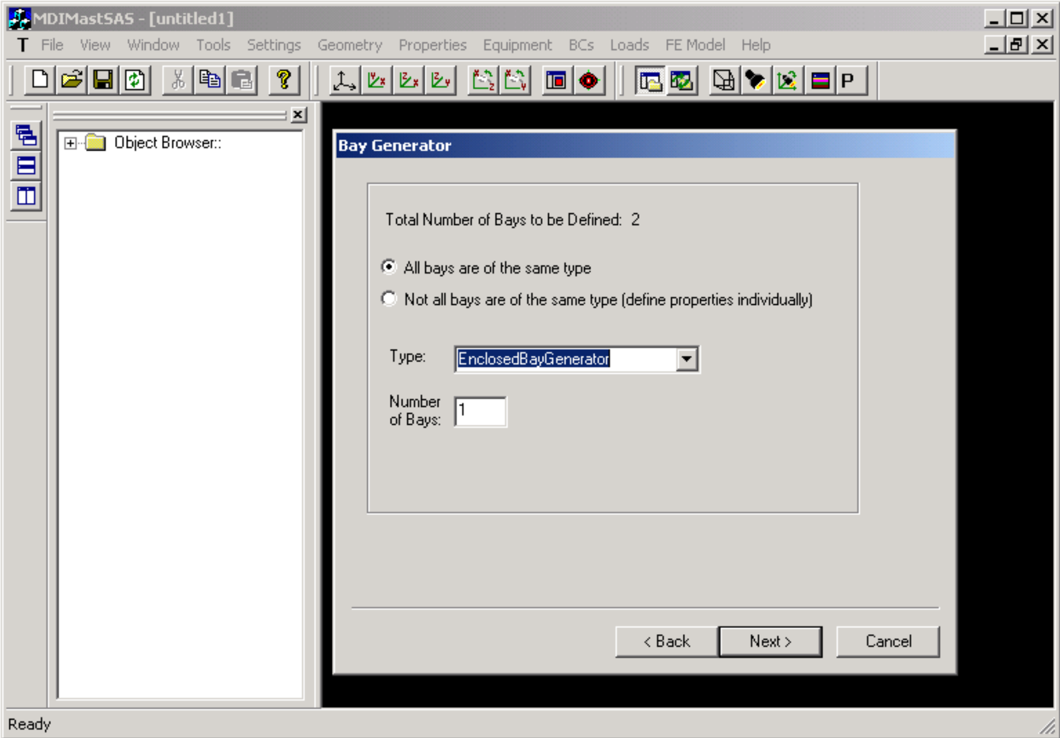



**Figure 3.5: Generation of enclosed bays for main mast section (simple enclosed mast)**

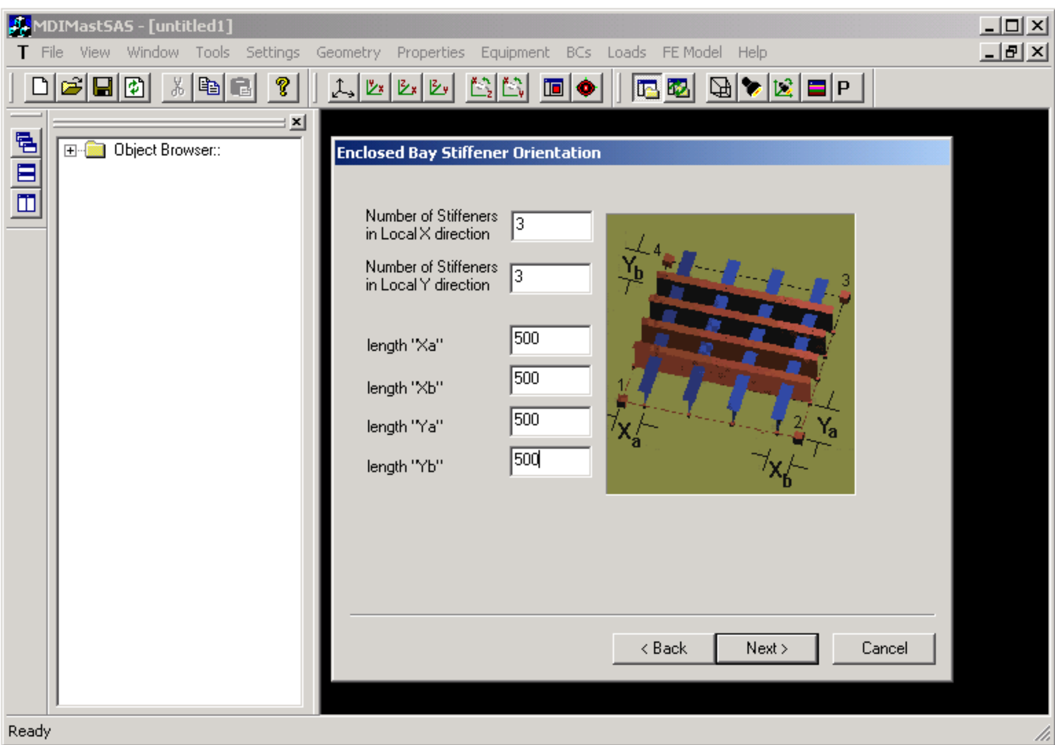



**Figure 3.6: Definition of stiffened panel layout details for bays of enclosed mast**

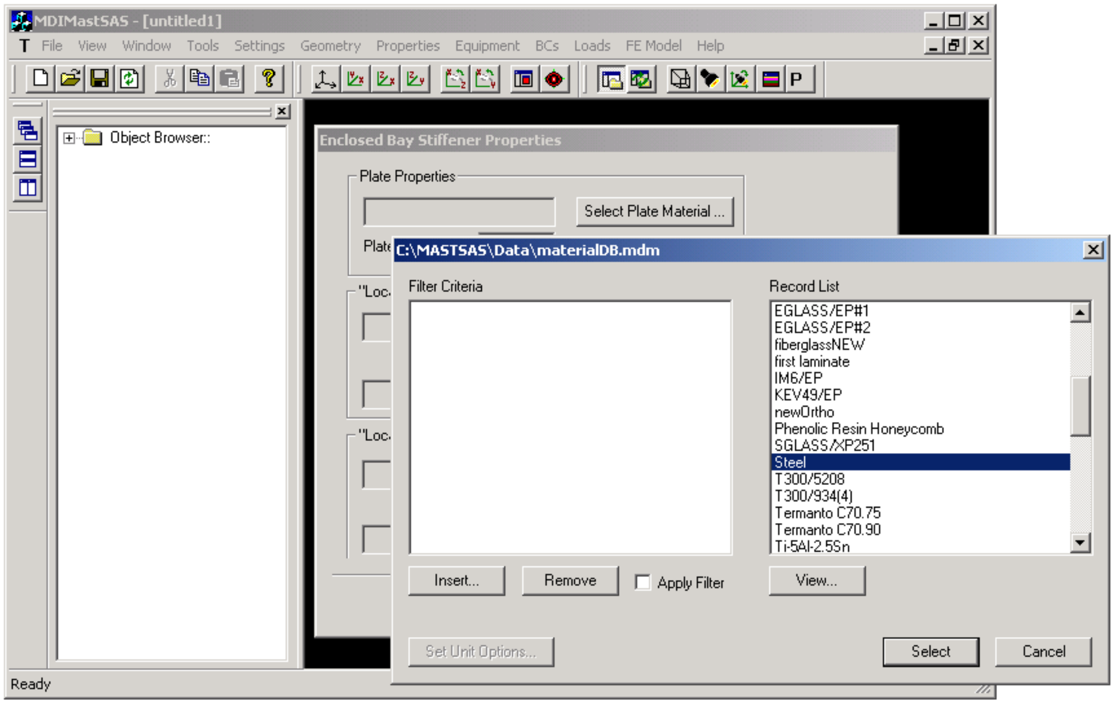



**Figure 3.7: Specification of material type for enclosed mast structure**

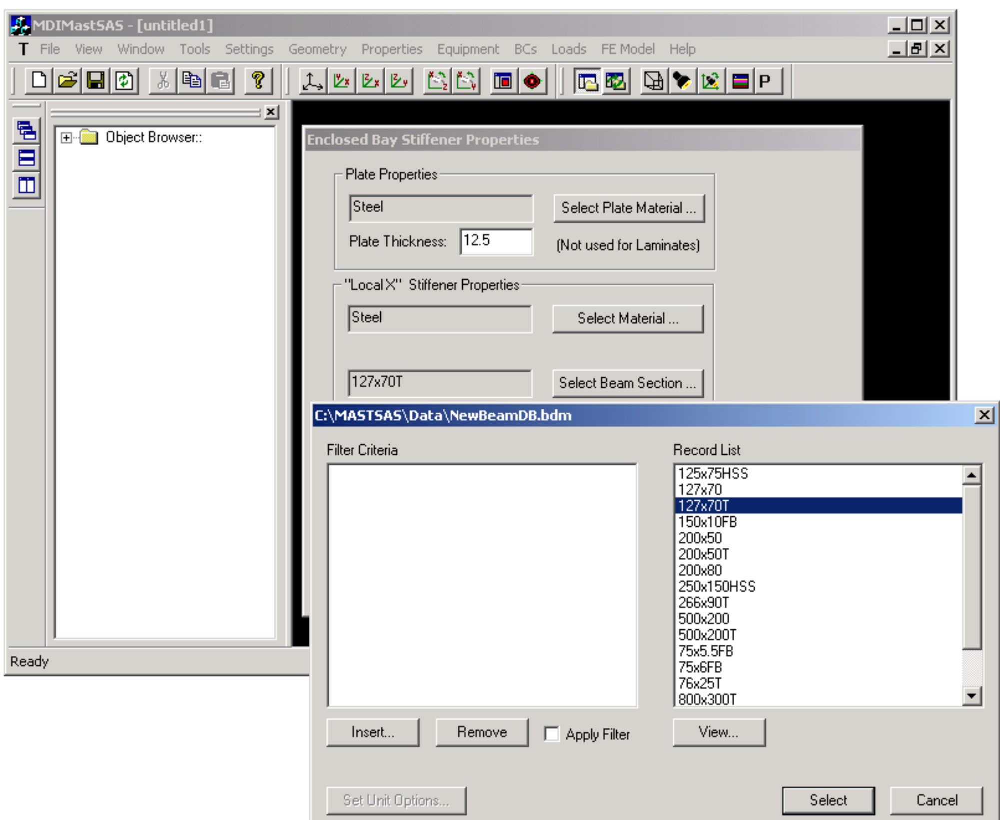



**Figure 3.8: Specification of plate and stiffener properties**

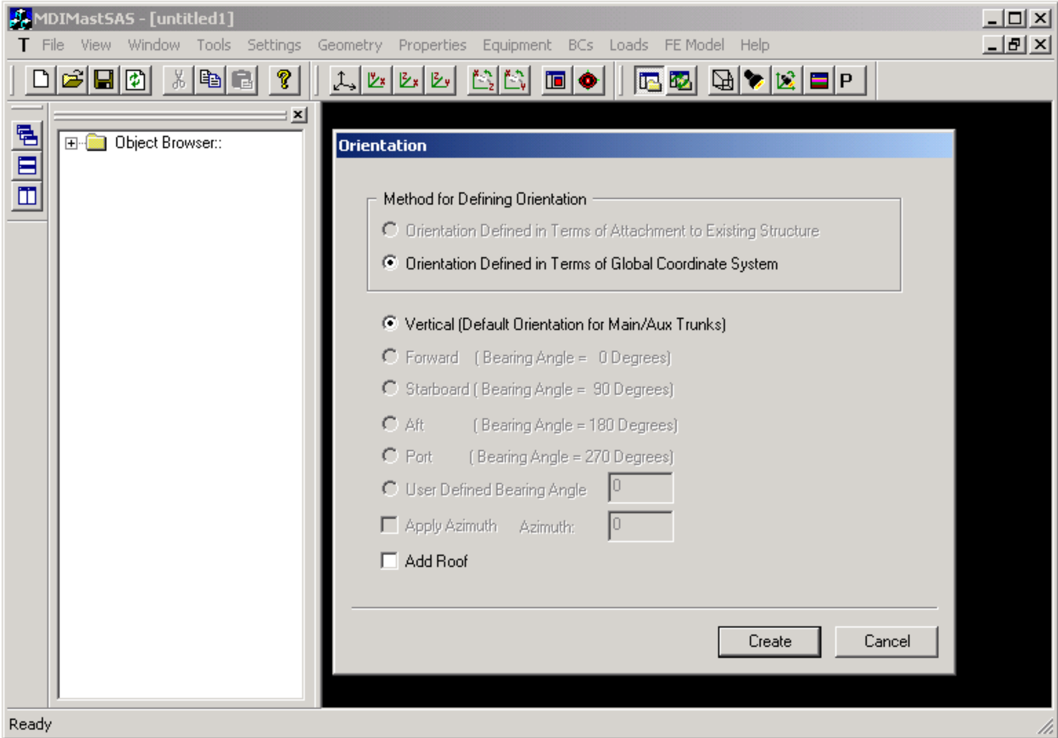



**Figure 3.9: Defining orientation of main mast section (simple enclosed mast)**

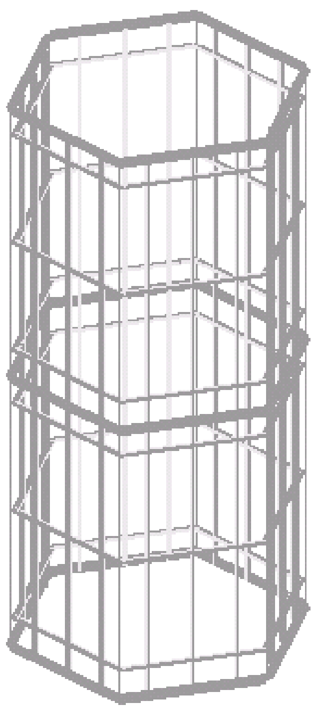


**Figure 3.10: Main mast section of simple enclosed mast model**

### 3.2.2 Generation of Interior Stiffened Panels, Cut-outs, and Roofs

A stiffened panel may be added to the mast structure at any elevation along its height, as well as any offset. Once the stiffened panel is created, a cut-out may be added. An interior stiffened panel, cut-out, and roof may be added to the mast structure using the following guidelines:

- a new stiffened panel is added at an elevation of 5m (i.e., main cross section 2)
- the panel consists of 12.5mm thick plating only
- a circular cut-out, 2m in diameter, is then added to the newly created panel
- finally, a roof is added to the structure by simply adding a new stiffened panel (again, plating only) at an elevation of 10m

It should be noted that stiffeners on panels of more than four sides cannot be modeled with the current version of MASTSAS, whereas unstiffened panels of any configuration may be incorporated.

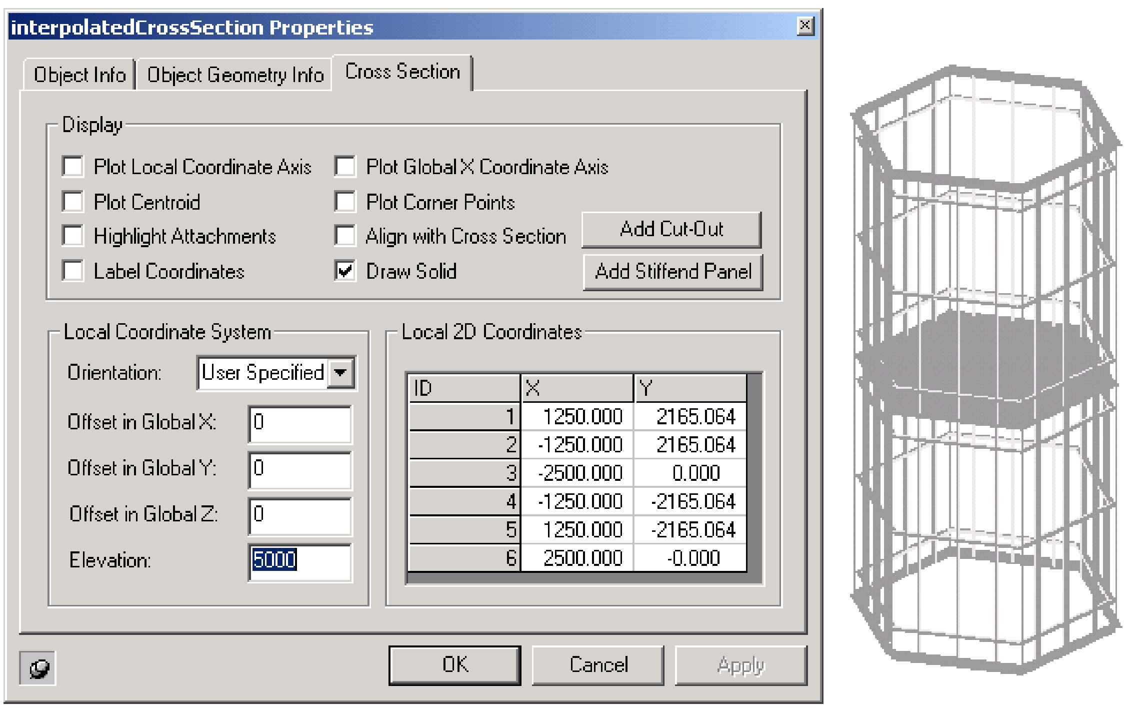



**Figure 3.11: Adding a stiffened panel at an intermediate elevation**

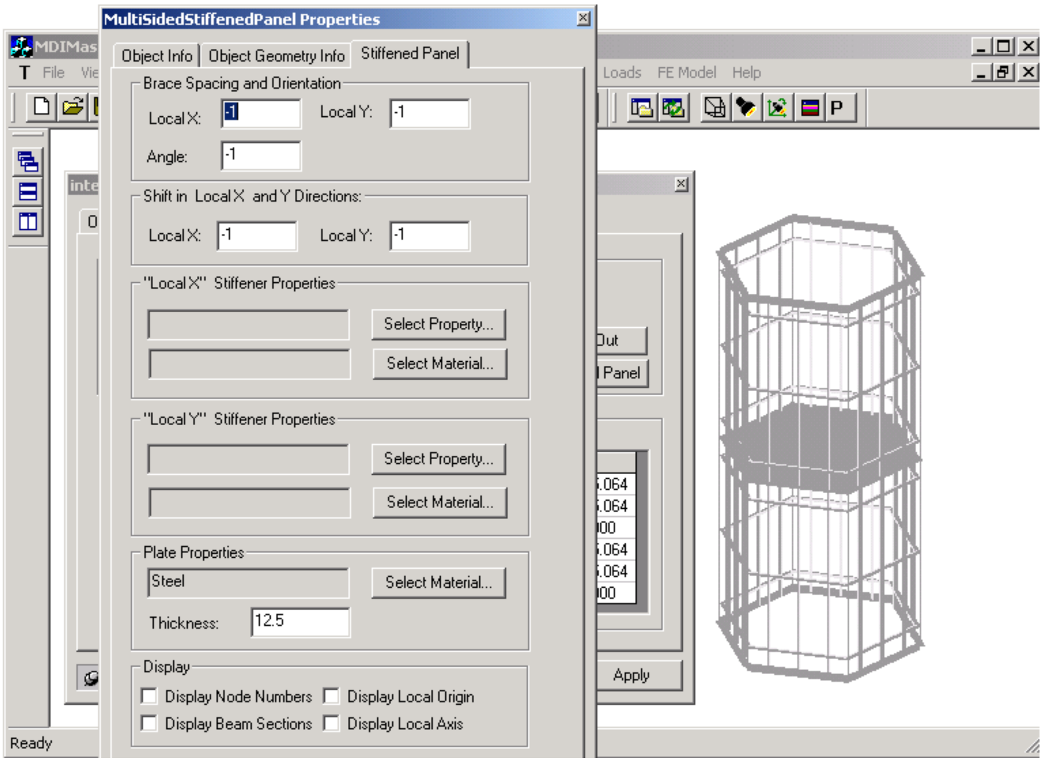



Figure 3.12: Definition of interior stiffened panel properties

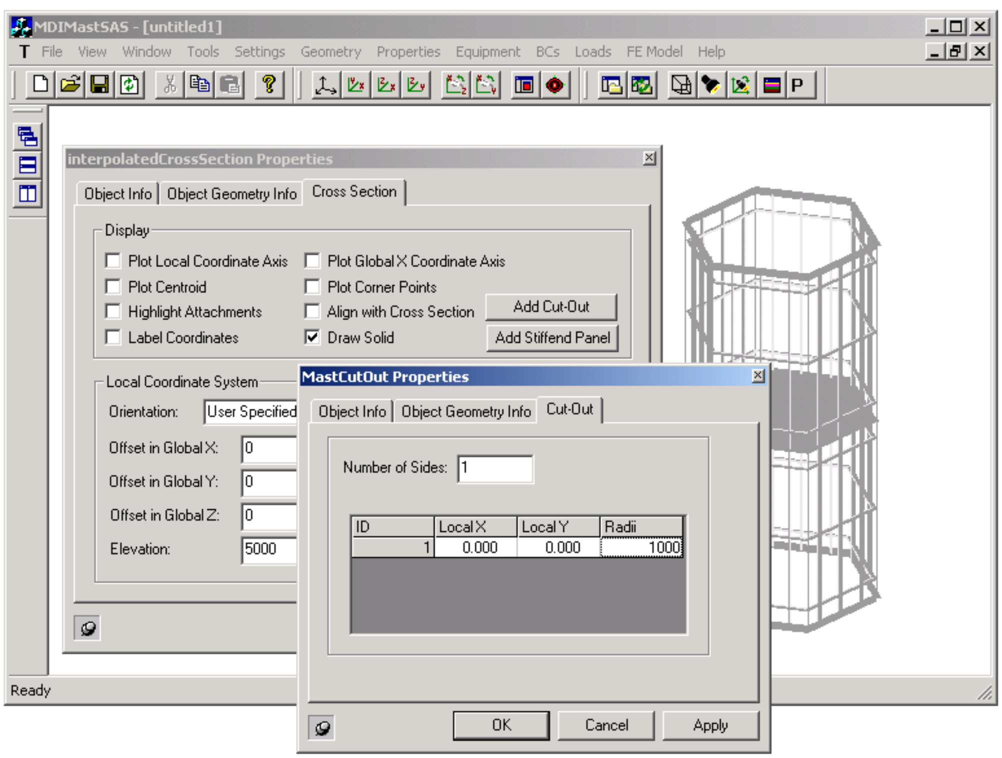



Figure 3.13: Definition of panel cut-out properties

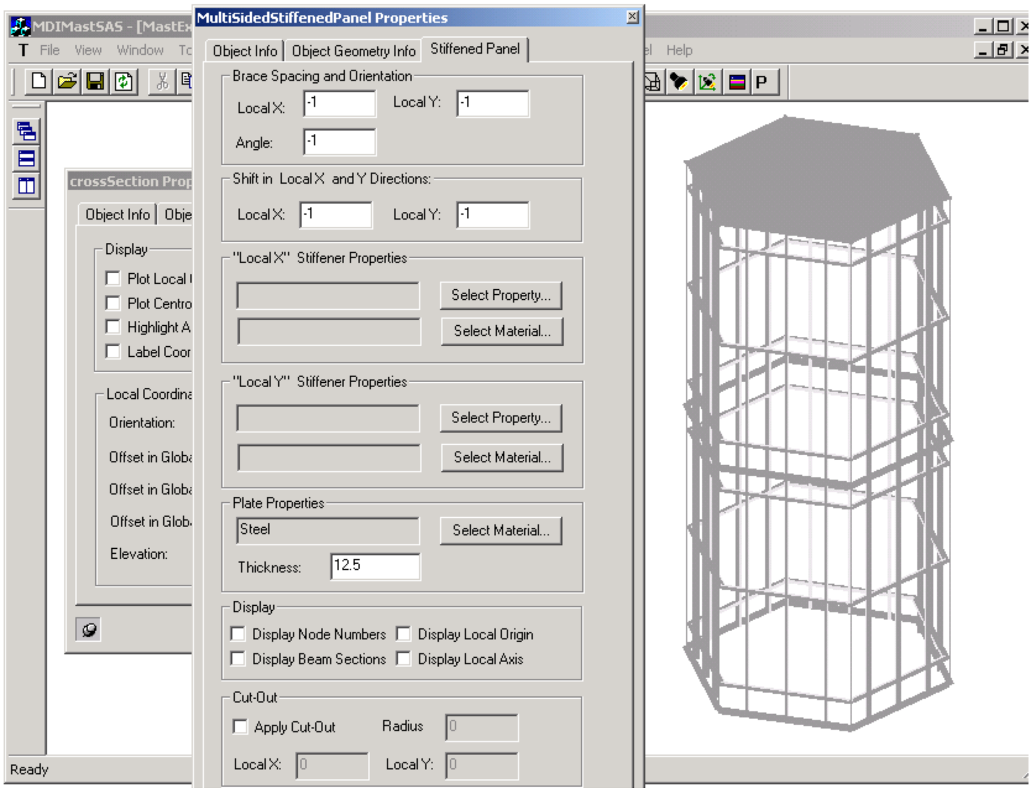



**Figure 3.14: Adding a roof to the enclosed mast structure**

## 3.3 Application of Boundary Conditions

The enclosed mast structure will be restrained using fixed boundary conditions, applied to the nodes defining the base cross section. For ease of nodal picking, the node size may be increased using MASTSAS' '*Draw Size*' feature. Application of these boundary conditions is shown in the figures below.

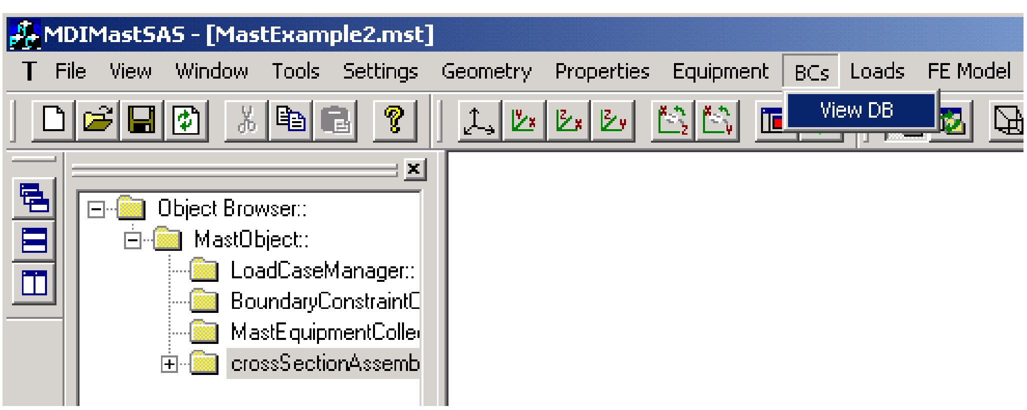



**Figure 3.15: Application of new boundary conditions**

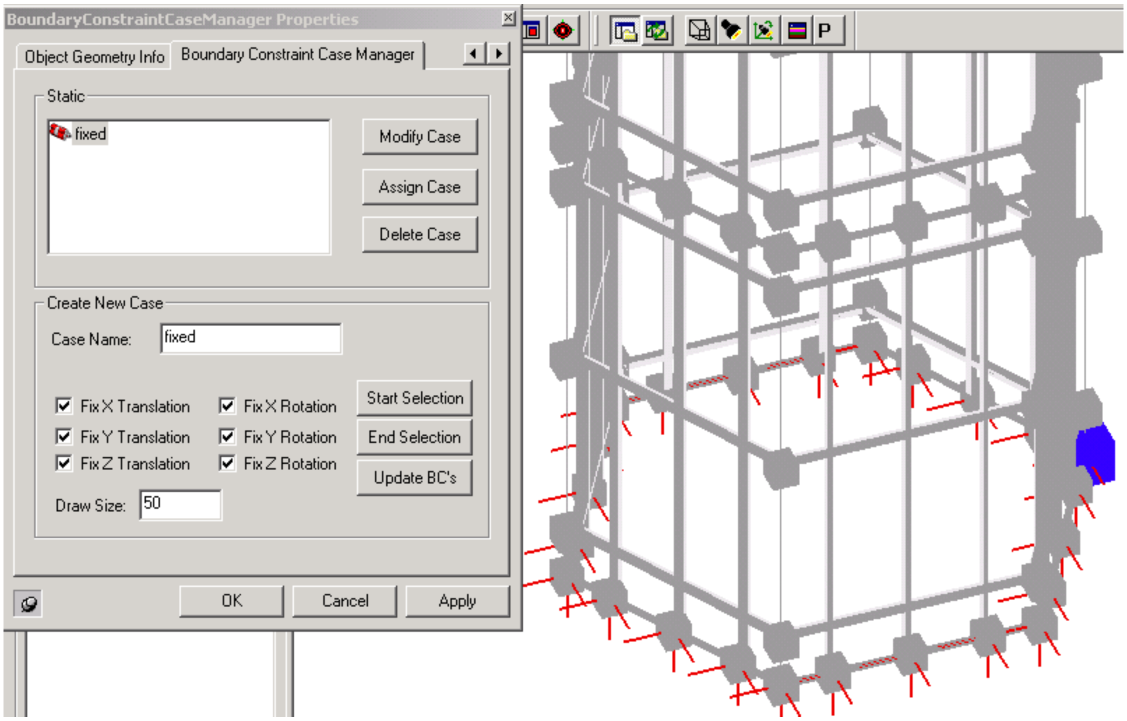



**Figure 3.16: Nodal identification (blue) for application of boundary conditions**

## 3.4 Generation and Application of Model Loads

In this second example, the enclosed mast structure is subjected to environmental loading. Application of the appropriate loading is accomplished by:

- evoking the 'Loads' option from MASTSAS' main menu
- assigning a 'new' load case, and
- selecting 'Wind Load' from the load options available

Generation and application of environmental loading is shown in the figures below.

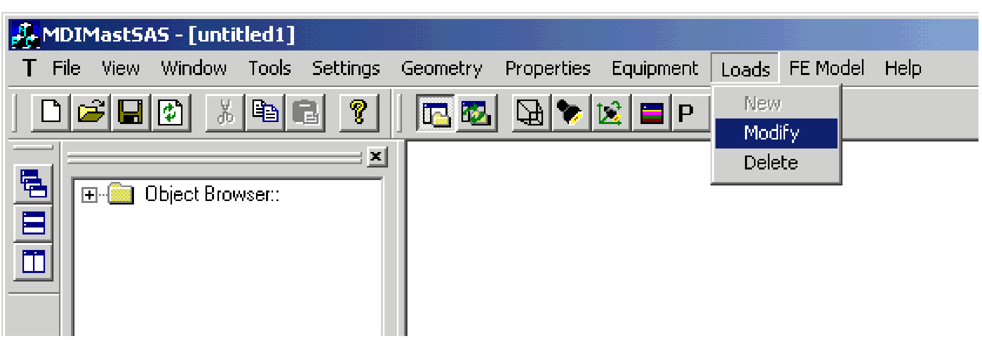



**Figure 3.17: Launching MASTSAS' *LoadCaseManager***

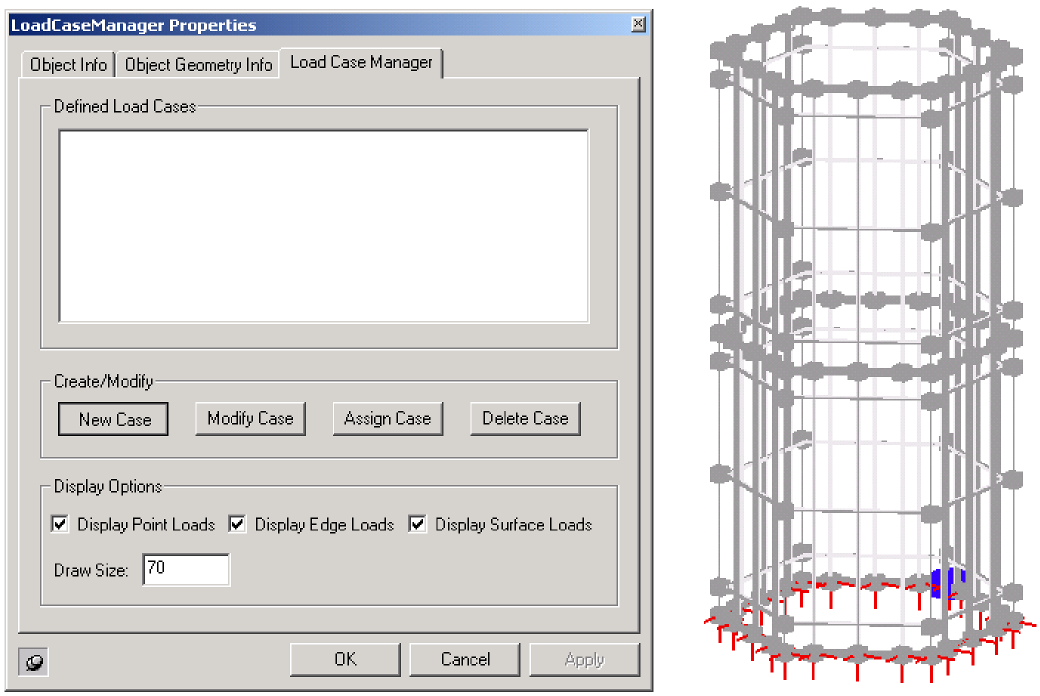



**Figure 3.18: Definition of new load case (simple enclosed mast)**

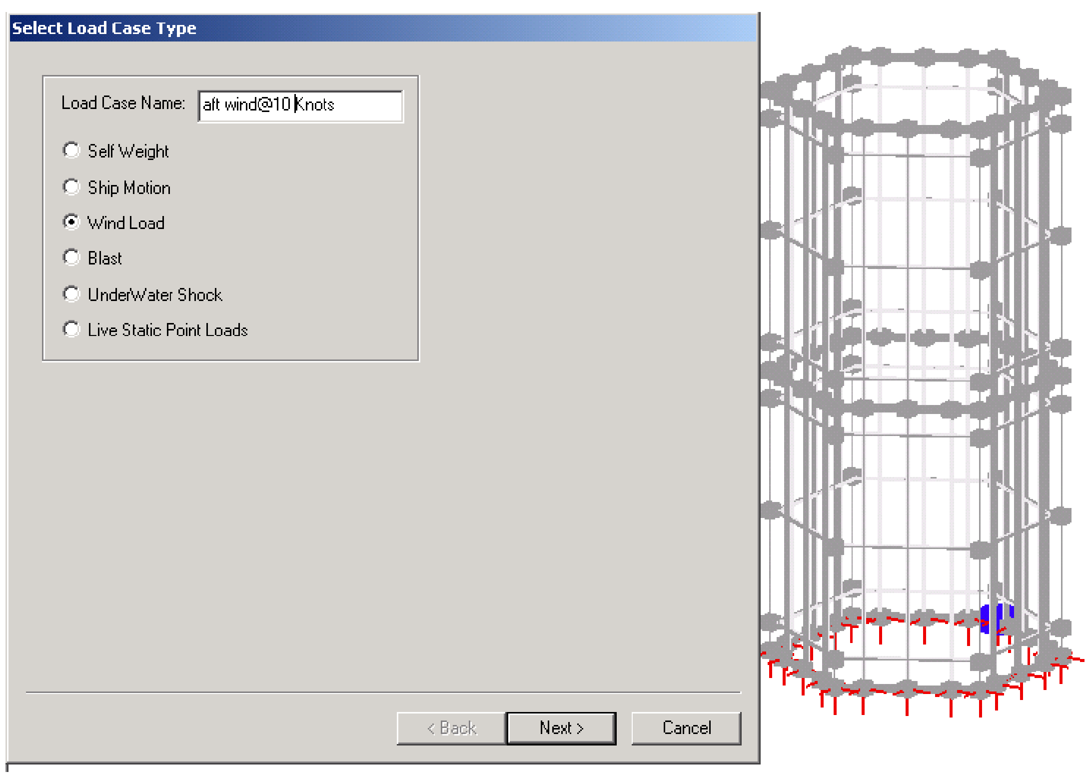



**Figure 3.19: Description of wind loading on mast structure**

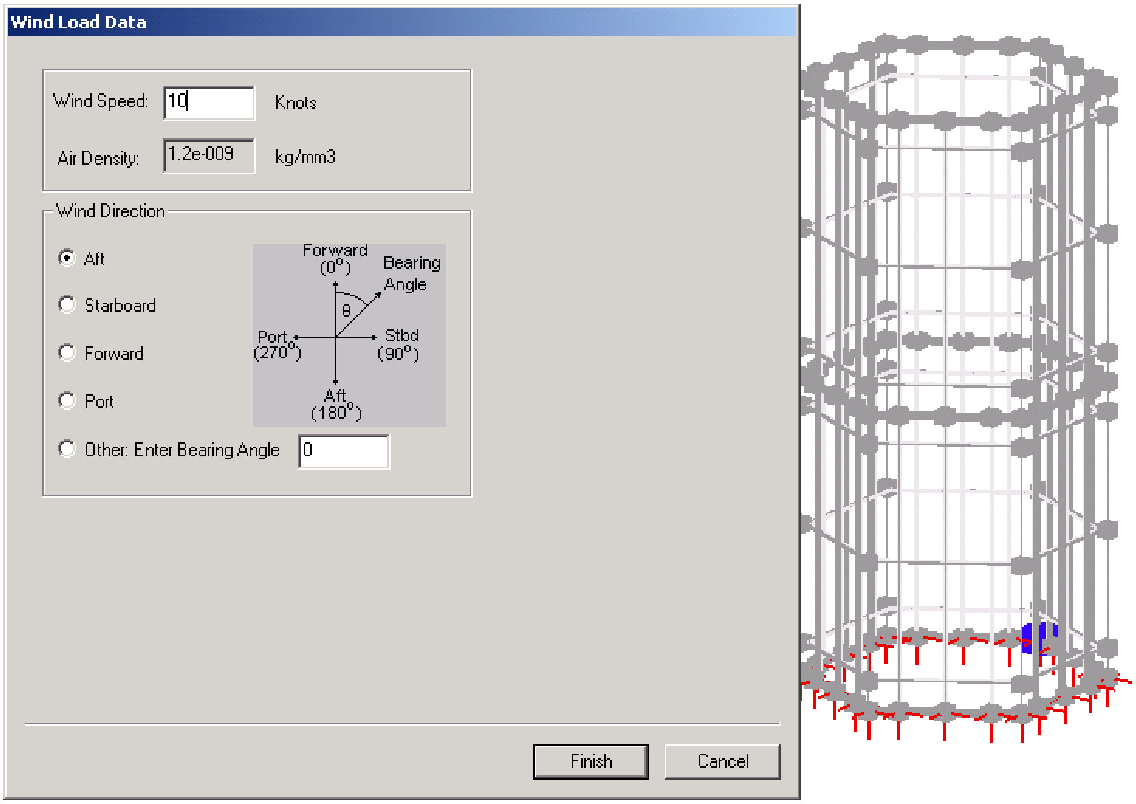



**Figure 3.20: Wind loading details**

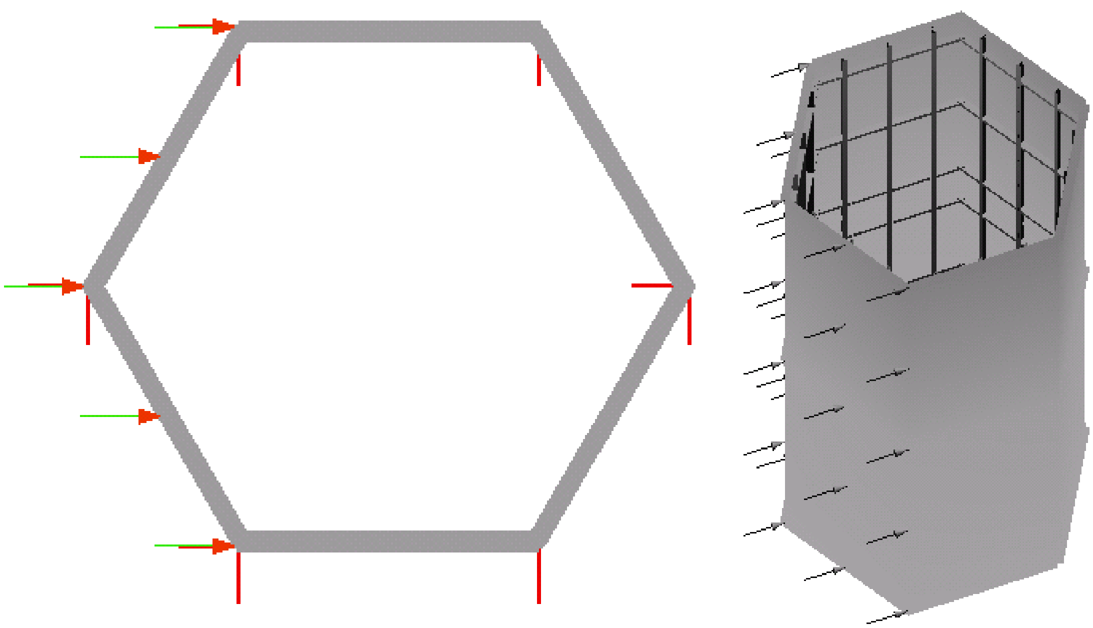


**Figure 3.21: Resulting wind loading on mast structure**

## 3.5 Finite Element Modeling

A finite element model of the mast structure can be generated using MASTSAS' '*Boundary FE Detail*' features. The following guidelines may be used to produce a suitable mesh and prepare an appropriate input file for the DSA/VAST solver:

- set the '*Create Mesh Flag*' and select the '*Hidden Line Mesh*' option from the display mode features
- export the model mesh to a DSA database format

MASTSAS' finite element modeling procedures are described in the figures below.

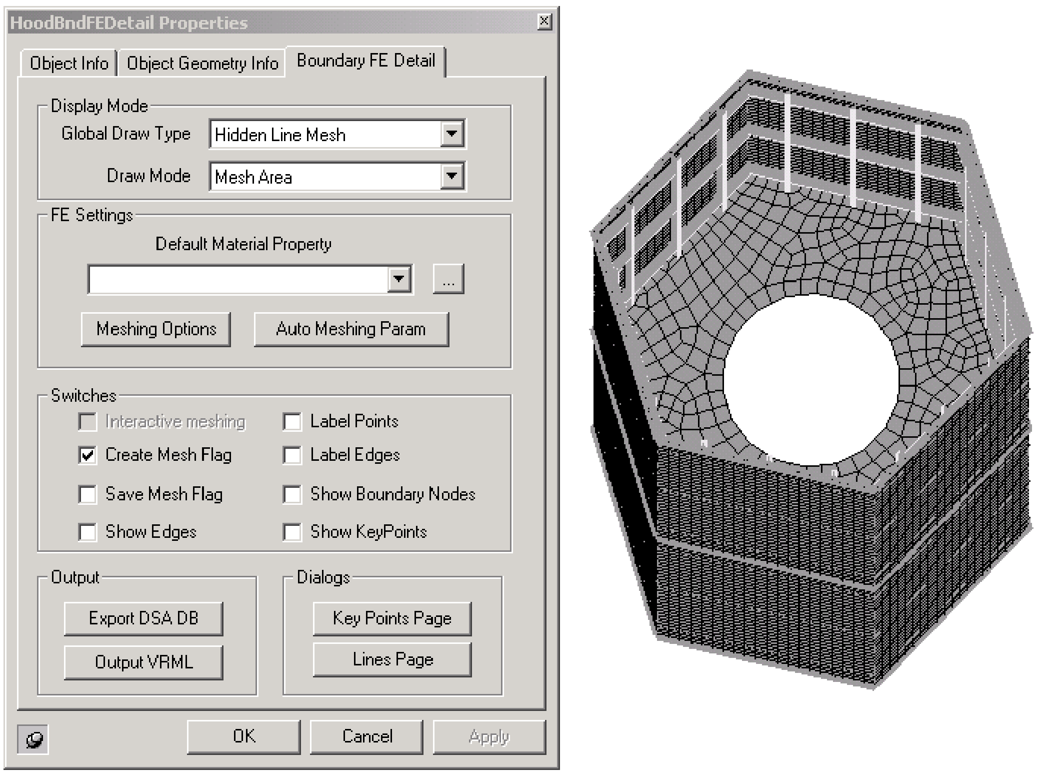



**Figure 3.22: Finite element model of simple enclosed mast structure showing interior stiffened panel cut-out**

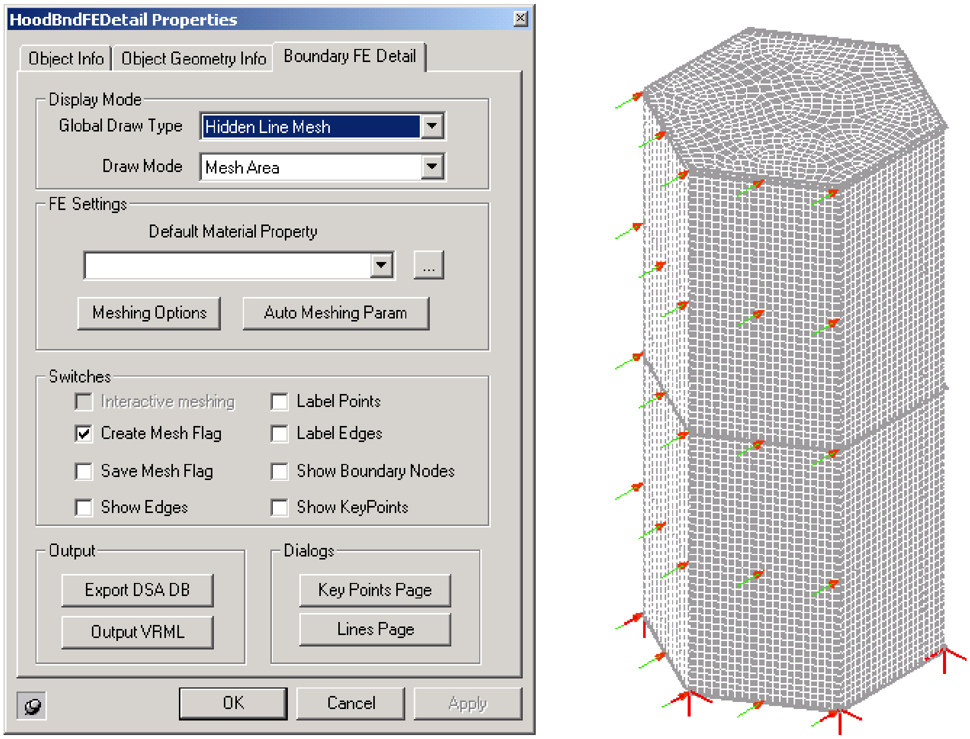



**Figure 3.23: Finite element model of entire mast structure, showing boundary conditions and applied loading**

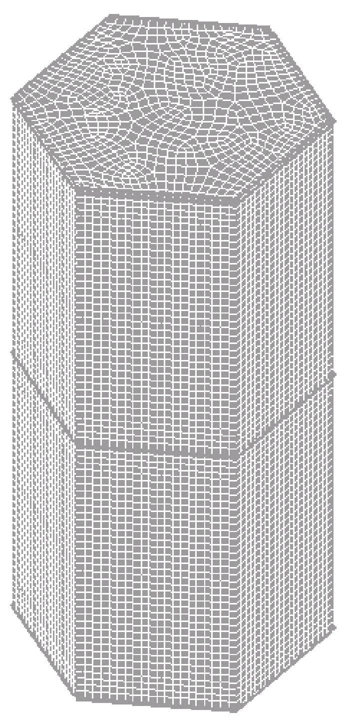


**Figure 3.24: Resulting finite element mesh of simple enclosed mast structure**

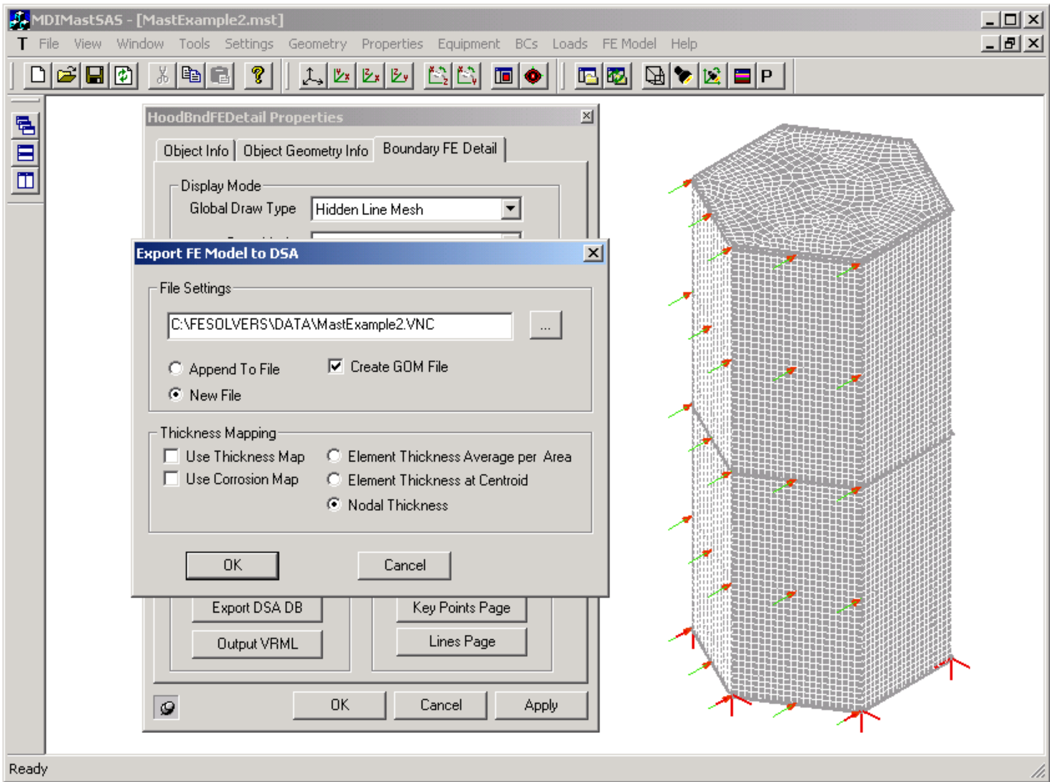



**Figure 3.25: Generation of DSA database file (simple enclosed mast)**

## 3.6 Analysis

Details of the analysis are then prepared by selecting the '*Analysis Setup*' option under the '*FE Model*' tab of the main menu, as shown in Figure 3.26. The appropriate analysis options are then selected from the pop-up menu illustrated in Figure 3.27.

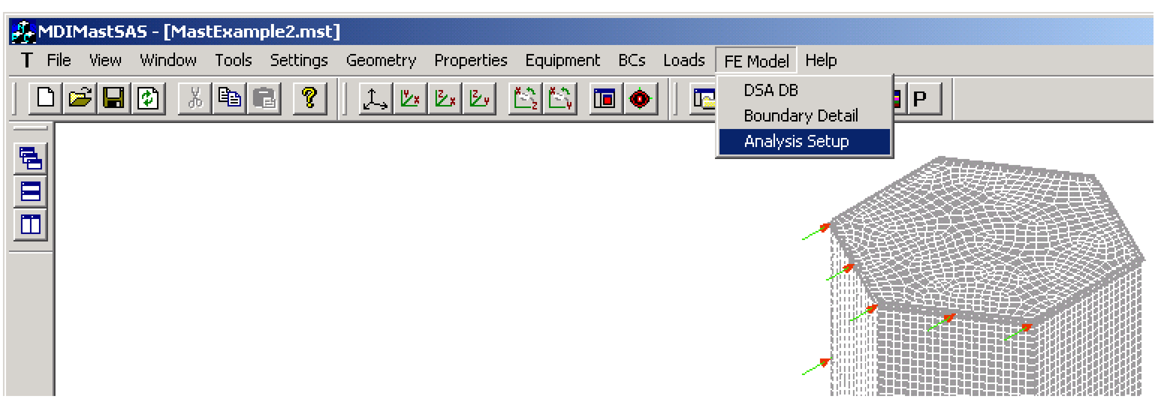



**Figure 3.26: Finite element analysis setup**

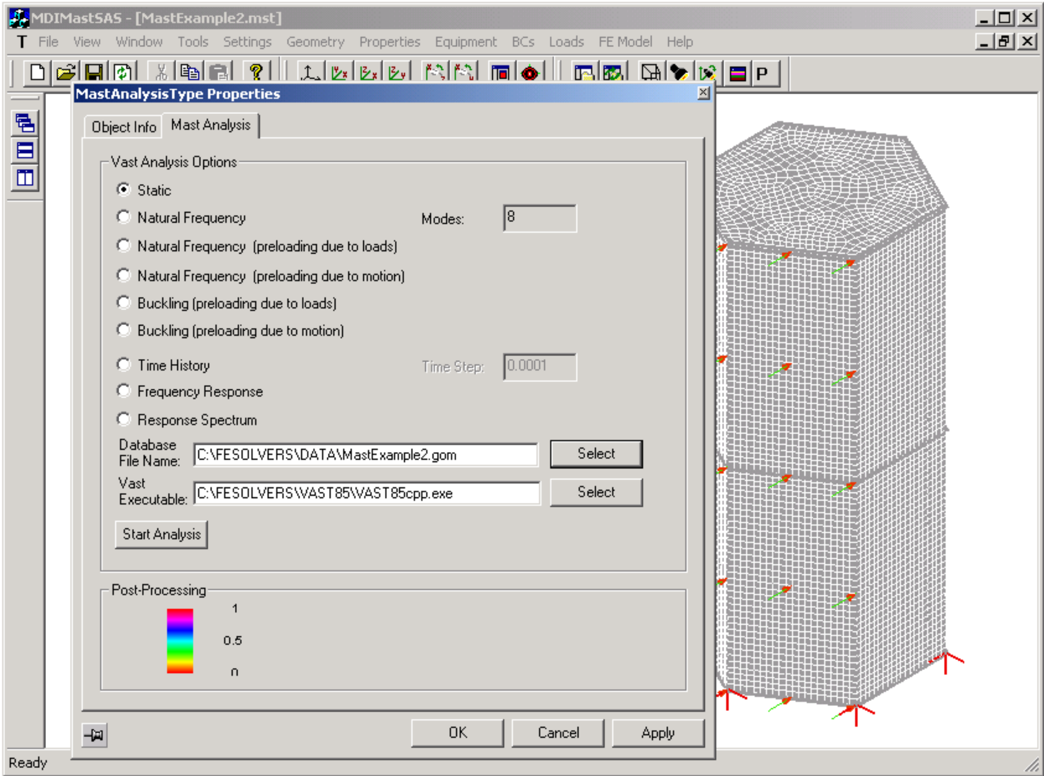



**Figure 3.27: Finite element analysis details**

# 4. ANALYSIS OF THE EVENT DICETHROW MAST (EXAMPLE 3)

## 4.1 Problem Description

This example represents application of the MASTSAS system to a configuration previously investigated by Norwood (1977), and tested by DRDC-Suffield (formerly DRES) at Event Dicethrow. As such, the configuration will be referred to as the Event Dicethrow Mast. This real-life mast structure was selected in order to validate the integrity of the MASTSAS modeling and analysis capabilities.

## 4.2 Notable MASTSAS Features

In order to facilitate the deletion of braces from main trunks and yardarms, MASTSAS provides a feature which allows users to select braces using the mouse and send them to a "trash bin" (see Figure 4.1). The trash bin concept also provides users with a means to recover braces tagged for deletion. MASTSAS also provides a capability that allows for the addition of the mass associated with gusset plates (see Figure 4.2).

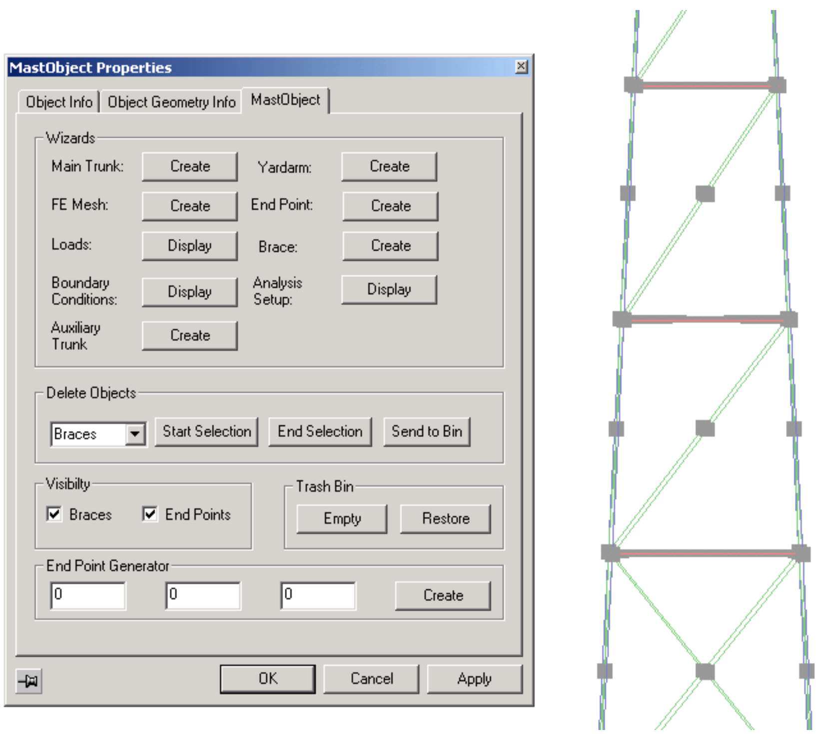



**Figure 4.1: Feature for deleting braces**

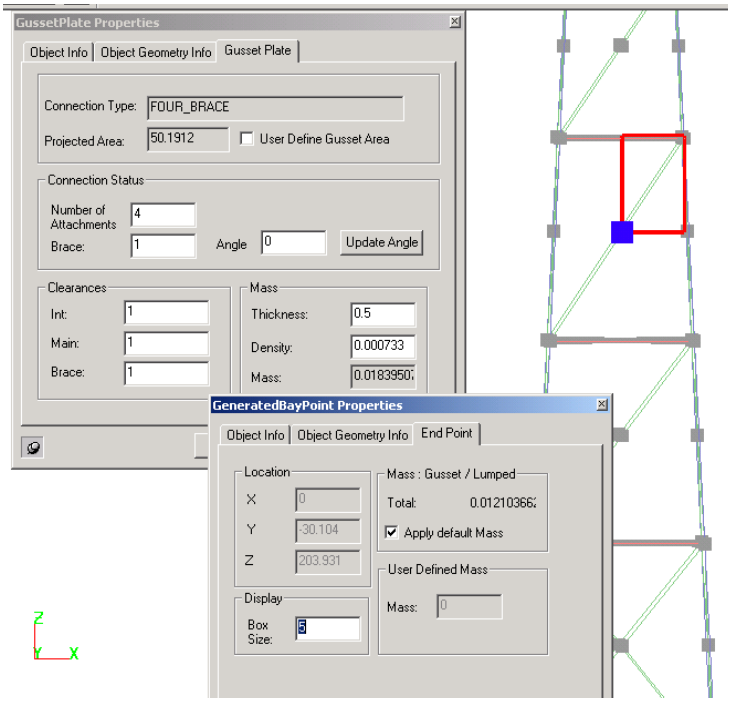



**Figure 4.2: Optional gusset plate mass feature**

## 4.3 Model Development

Details concerning the mast geometry, along with the engineering properties of all materials and structural members, were obtained through a review of the report by Norwood (1977). All required model information is presented in a series of detailed drawings, included in Appendix A. The relationship between the cartesian coordinate system and the ship axes system is shown in Figure 4.3.

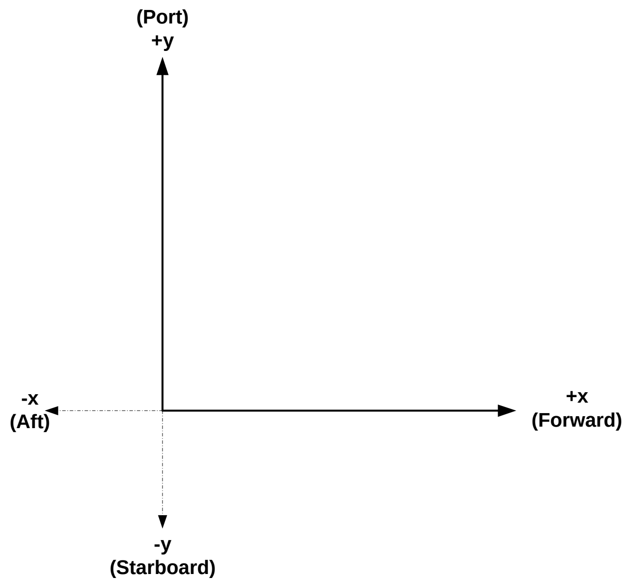



**Figure 4.3: Cartesian coordinate system versus ship axes system**

The main mast extends 30ft (360in) in height, with its base cross section (CS01) measuring 6ft x 7ft (72in x 84in) and its top-most cross section (CS06) measuring 3ft x 3.5ft (36in x 42in). Interpolated cross-sections were defined at elevations of 7ft (84in) (CS02), 13.5ft (162in) (CS03), 20ft (240in) (CS04), and 25.5ft (306in) (CS05). A forward-facing 'degenerated' yardarm, meaning the height of its outer-most cross-section is zero, is attached to the top-most bay of the main mast, measuring 6.5ft (78in) in length (with respect to the forward edge of the top-most cross section on the main mast). In defining the yardarm, interpolated cross-sections were identified at elevations of 2.5ft (30in) and 4.5ft (54in). The mast structure's main trunk and yardarm were both generated using MASTSAS' automated modeling wizards. The configuration of each mast component was modeled assuming a Type 'A' lattice configuration. MASTSAS' 'brace deletion' feature was then used to delete the appropriate cross bracing throughout the main trunk and yardarm, thus arriving at the configuration shown in Figure 4.4 (see Appendix A). As member sizing varied considerably throughout the structure, all legs and cross bracing in the model were verified to ensure their sizes had been correctly selected. All members of the main mast and yardarm were constructed of high-strength steel, the properties of which are summarized in Table 4.1.

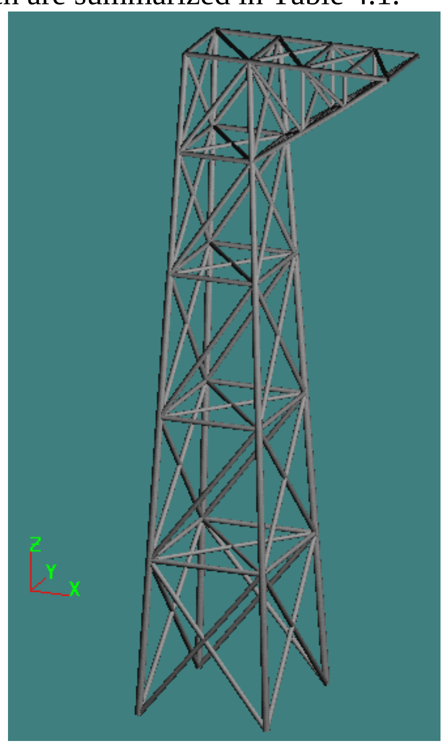



**Figure 4.4: Main mast and yardarm of the Event Dicethrow Mast**

Finally, an antenna structure was added to the starboard side of the mast yardarm, spanning its two outer-most bays. The 0.5in thick antenna plate measures 4ft x 4ft (48in x 48in), and is stiffened in either direction by three evenly spaced 4in x 4in x ¼in hollow structural sections. The panel is supported by a simple three-frame truss structure, the members of which are comprised of 2.875in outer diameter Schedule 40 Piping. All members of the stiffened panel, adjoining brace structure, and plating are comprised of

standard strength steel, with properties summarized in Table 4.1. The final mast configuration and antenna structure are shown in Figures 4.5 and 4.6.

**Table 4.1: Material properties for steel used in the Event Dicethrow Mast**

| | E (psi) | $\nu$ | $\rho$ (lb $s^2/in^4$) | $\sigma_{yld}$ (ksi) |
|---|---|---|---|---|
| High Strength Steel | $29x10^6$ | 0.30 | $0.733x10^{-3}$ | 58.0 |
| Regular Strength Steel | $29x10^6$ | 0.30 | $0.733x10^{-3}$ | 43.5 |

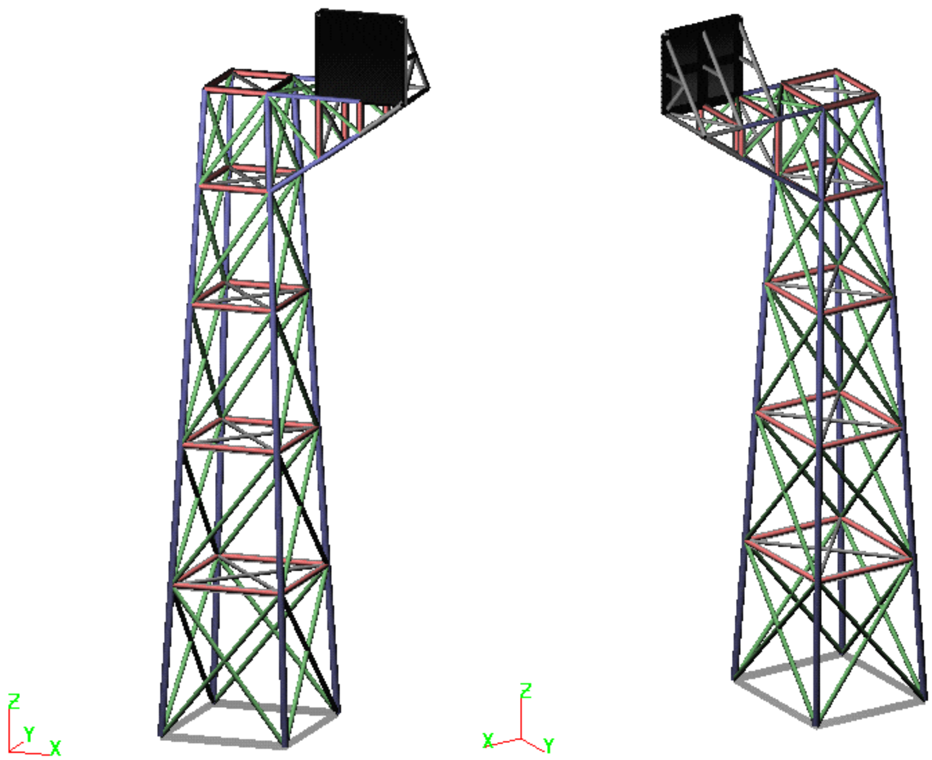



**Figure 4.5: Final configuration for Event Dicethrow Mast**

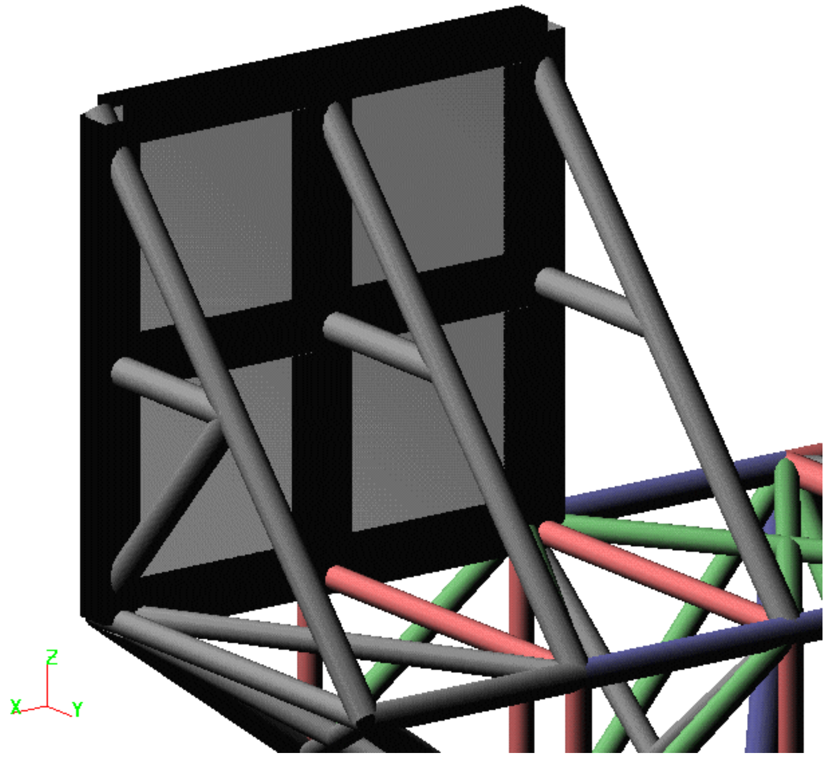



**Figure 4.6: Antenna structure for Event Dicethrow Mast**

Boundary conditions were then applied to the structure, assuming the base to be completely restrained against both translation and rotation. After specifying a default element size of approximately 2”, a finite element mesh of the Dicethrow Mast was generated using MASTSAS’ automatic mesher. The finite element model was then exported as a DSA database, which could then be used to run the desired VAST finite element analyses.

The time required to generate the entire model, apply boundary conditions, generate a suitable finite element mesh of the structure, and prepare the VAST input files required for the eigenvalue and static analyses was approximately 15-20 minutes.

## 4.4 Analysis

### 4.4.1 Eigenvalue Analysis

The final mast configuration was first analyzed to determine its natural frequencies. To facilitate comparison with results reported by Norwood (1977), the antenna structure was modeled two ways. In addition to modeling the antenna structure as depicted above, it was also modeled using its equivalent mass (approximately 2.0 $lb \cdot s^2 / in^4$) centered over the two outer-most bays of the yardarm at a height of 2ft (24in). This added mass was supported by the truss structure shown in Figure 4.7 below. A negligible mass was assumed for the members comprising this supporting structure, so as not to affect the

overall frequency response of the structure. This modelling option was selected to establish a direct comparison with the work of Norwood (1977).

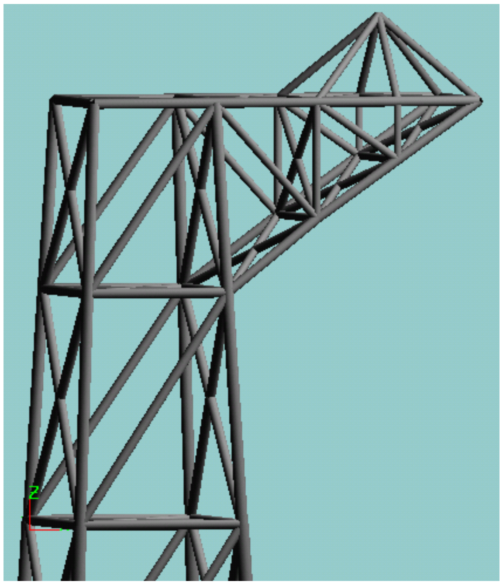
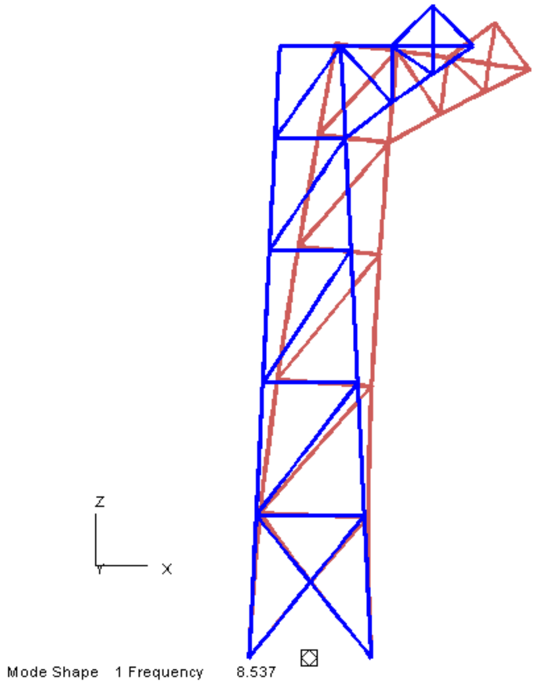


**Figure 4.7: Supporting structure for Event Dicethrow antenna simulated using equivalent mass**

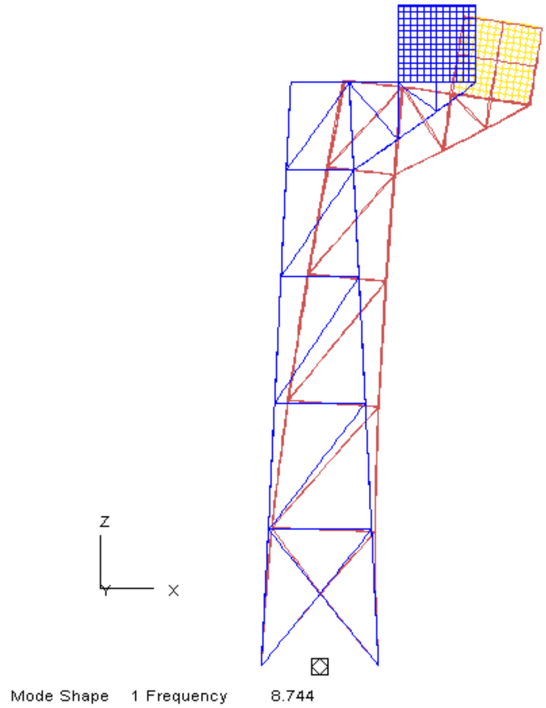
The resulting natural frequencies and mode shapes are summarized in Table 4.2, along with those obtained for the actual Event Dicethrow mast and the associated predictions reported by Norwood (1977) (based on the MASTD system). The fundamental frequency of 8.74 Hz (natural period, T=0.114s) predicted by MASTSAS compares well with MASTSAS predictions for the simulated antenna and those reported by Norwood (1977). The first two modal shapes are illustrated in Figures 4.8 and 4.9.

**Table 4.2: Comparison of Natural Frequencies (Hz) for the 'Event Dicethrow' Mast**

| Mode No. | Description of Vibration Mode | MASTSAS | | MASTD | Measured |
|---|---|---|---|---|---|
| | | Simulated Antenna | Actual Antenna | | |
| 1 | Flexural Mode, Vibration @ y-axis | 8.54Hz | 8.74Hz | 8.68Hz | - |
| 2 | Flexural Mode, Vibration @ z-axis | 10.07Hz | 10.29Hz | 9.94Hz | 10.50Hz |
| 3 | Torsional Mode | 21.73Hz | 21.17Hz | 21.80Hz | 23.00Hz |
| 4 | 2nd Flexural Mode @ y-axis | 28.20Hz | 28.04Hz | 28.40Hz | 31.00Hz |

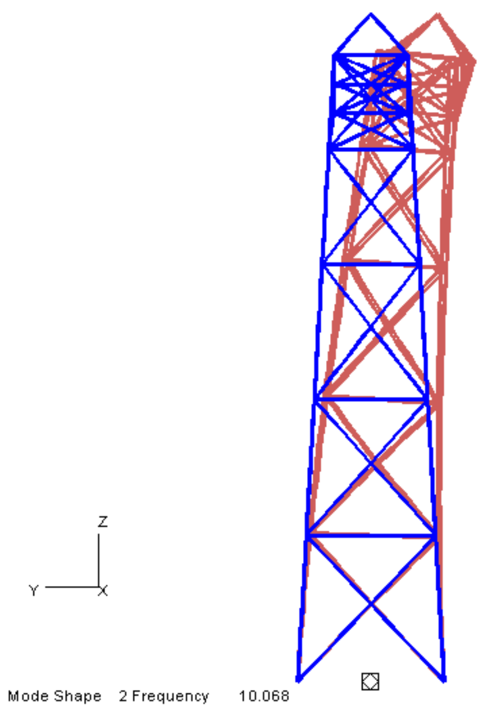



(a)

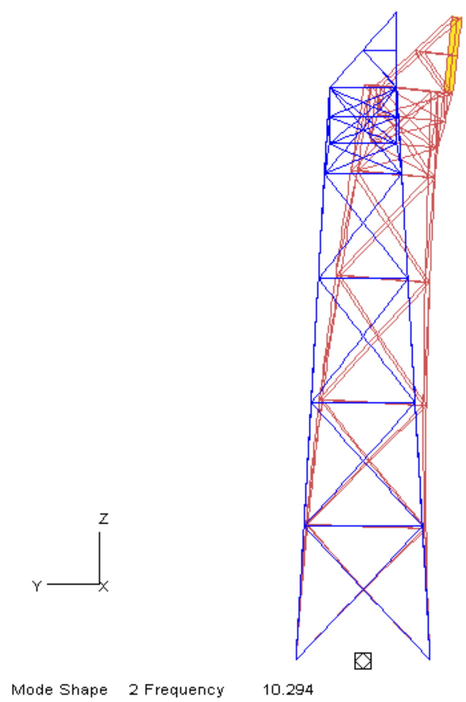



(b)

**Figure 4.8: Fundamental mode of vibration for Event Dicethrow Mast with (a) simulated antenna structure, and (b) actual antenna structure**




(a)




(b)

**Figure 4.9: Second mode of vibration for Event Dicethrow Mast with (a) simulated antenna structure, and (b) actual antenna structure**

The gusset plate masses computed by MASTSAS were compared to those predicted by Norwood (1977), and found to be in reasonable agreement in some instances (see Table 4.3). As suggested by the similar natural frequency predictions, small discrepancies seem to be relatively insignificant in this case, possibly due to the relatively few gussets in the overall structure.

**Table 4.3: Gusset plate mass predictions**

| Node ID* | Gusset Plate Mass (lbs) | |
|---|---|---|
| | MASTSAS | Norwood (1977) |
| 9 | 73.7 | 46.9 |
| 5 | 7.6 | 17.7 |
| 3 | 18.7 | 20.8 |
| 22 | 5.8 | 17.7 |
| 37 | 37.7 | 26.1 |
| 39 | 9.7 | 14.2 |
| 50 | 10.2 | 14.2 |
| 54 | 34.7 | 29.9 |

* - Refer to Appendix A for node numbering scheme

### 4.4.2 Static Analysis

A static analysis was then performed assuming that a static load of 4593lbs was applied along the aft edge of top-most cross section of the mast (in the y-z plane) and directed at an angle of 30° to the horizontal. This results in the application of the force components $F_Y$=-2296.5lbs x cos30°=-1988.8lbs and $F_Z$=2296.5lbs x sin30°= 1148.3lbs at both the port and starboard corners. The applied static loads are shown in Figure 4.10 below.

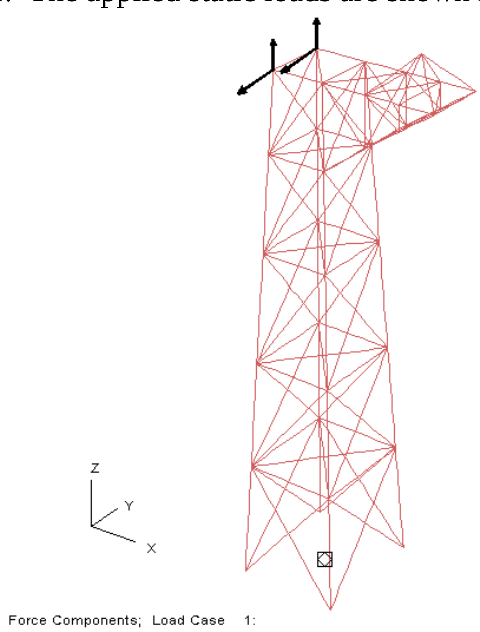



**Figure 4.10: Static loads applied to Event Dicethrow Mast**

The resulting member (maximum) static strains were then compared against to those reported for the actual Event Dicethrow Mast and associated predictions by Norwood (1977). The comparison is shown in Table 4.4 below for a select group of mast members. A contour plot of member strains (showing the location of members referred to in Table 4.4) is presented in Figure 4.11. A reasonable agreement is observed between the MASTSAS results and those obtained by Norwood (1977).

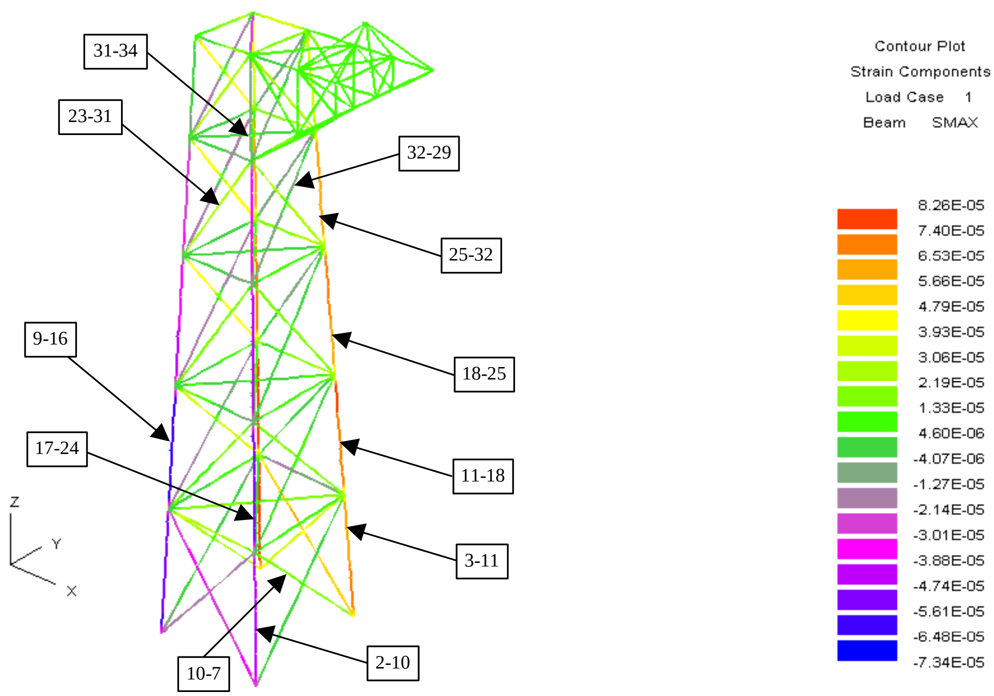



**Figure 4.11: Maximum strain contours for Event Dicethrow Mast**

**Table 4.4: Maximum static strains (με) for Event Dicethrow Mast**

| Member ID* | Description | Maximum Strain (με) | | |
|---|---|---|---|---|
| | | MASTSAS * | MASTD | Measured |
| 2-10 | Forward-starboard leg of main trunk (first bay) | - 51.8 | - 57.2 | - 53.7 |
| 3-11 | Forward-port leg of main trunk (first bay) | +53.6 | +54.0 | +55.8 |
| 9-16 | Aft-starboard leg of main trunk (second bay) | - 69.3 | - 75.3 | - 76.4 |
| 11-18 | Aft-port leg of main trunk (second bay) | +60.4 | +57.8 | +59.0 |
| 17-24 | Forward-starboard leg of main trunk (third bay) | - 49.5 | - 54.3 | - 41.1 |
| 18-25 | Forward-port leg of main trunk (third bay) | +52.6 | +48.6 | +49.6 |
| 25-32 | Forward-port leg of main trunk (fourth bay) | +46.1 | +41.7 | +40.0 |
| 32-29 | Diagonal brace on forward face of main trunk (fourth bay) | - 9.7 | - 20.6 | - 18.8 |
| 10-7 | Diagonal brace on forward face of main trunk (first bay) | +9.0 | +11.5 | +10.5 |
| 31-34 | Horizontal brace at fourth (vertical) cross section | +1.15 | +2.10 | +2.00 |

*-Members are identified in terms of their associated endpoints (see Appendix A for illustrations showing endpoint node identification)

### 4.4.3 Blast Analysis

As Norwood (1977) presented blast-induced dynamic strain results for the Dicethrow Mast, a MASTSAS blast analysis was selected in order to confirm these results and validate the integrity of the software. It should be noted that due to the use of empirical relations and design charts, this version of MASTSAS requires that blast pressures be input in units of kilopascals (kPa) and temperatures be described in degrees centigrade (°C). The input parameters required for this analysis are described in Table 4.5.

**Table 4.5: Description of input parameters for blast analysis of the Dicethrow Mast**

| Parameter | Value |
|---|---|
| Blast Overpressure ($P_o$) | (10.1 psi) 69.7 kPa |
| Atmospheric Pressure ($P_a$) | (12.3 psi) 85.0 kPa |
| Dynamic Pressure Duration ($t_{dd}$) | 0.230 sec |
| Ambient Temperature ($T_o$) | 9.7 °C |
| Friedlander Decay Constant (k) | 0.95 |

Application of the blast loading is illustrated in Figure 4.12 below. The resulting time-displacement histories for various model nodes are shown in Figure 4.13. The location of the nodes indicated are summarized as follows:

- Node 2099 – center of the upper right quarter of the antenna plate
- Node 11 – top-most cross section of main mast (CS06), forward/port corner
- Node 55 – aft/port corner of CS05 of main mast
- Node 44 – forward/starboard corner of CS04 of main mast
- Node 41 – aft/port corner of CS03 of main mast
- Node 352 – forward/starboard corner of CS02 of main mast

The maximum displacement (1.041") was found at node 2099 at a time of 27.15ms. Table 4.6 compares the resulting peak dynamic strains for various mast members with those reported by Norwood (1977) for the actual Event Dicethrow Mast. The mast members consider are those referred to in Figure 4.11. In most cases, a reasonable agreement is observed between the MASTSAS results and those obtained by Norwood (1977). The axial strain-time histories for the elements considered are presented in Figure 4.14.

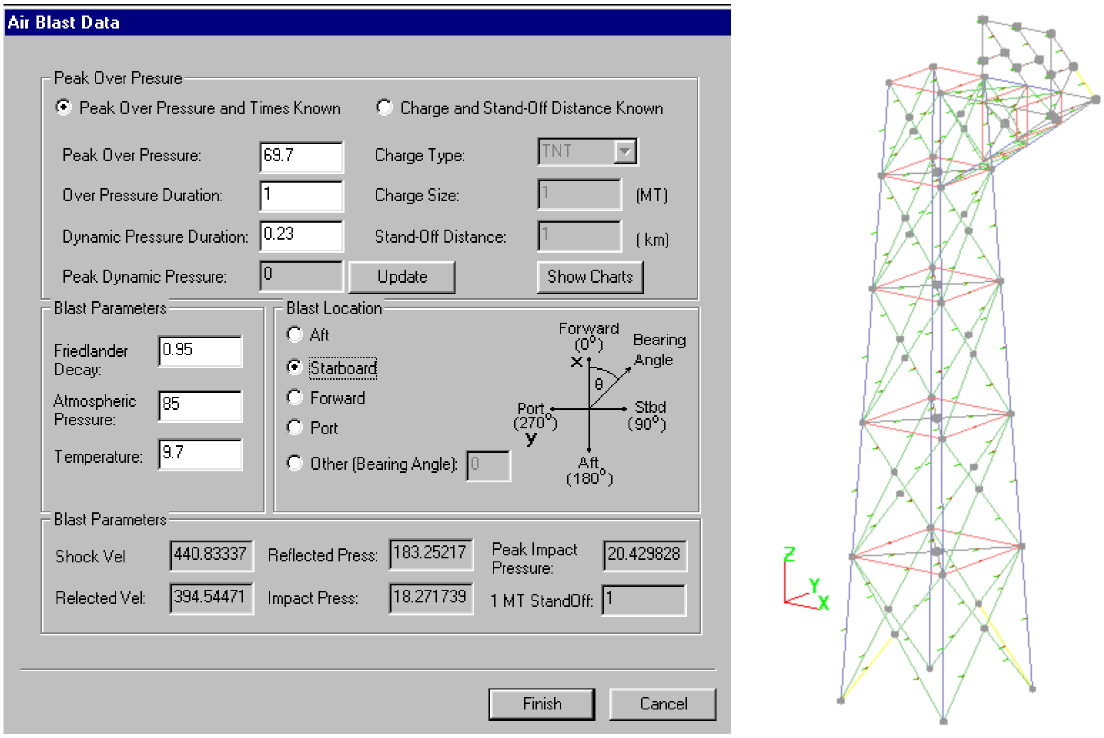



Figure 4.12: Blast overpressure applied to the Dicethrow Mast

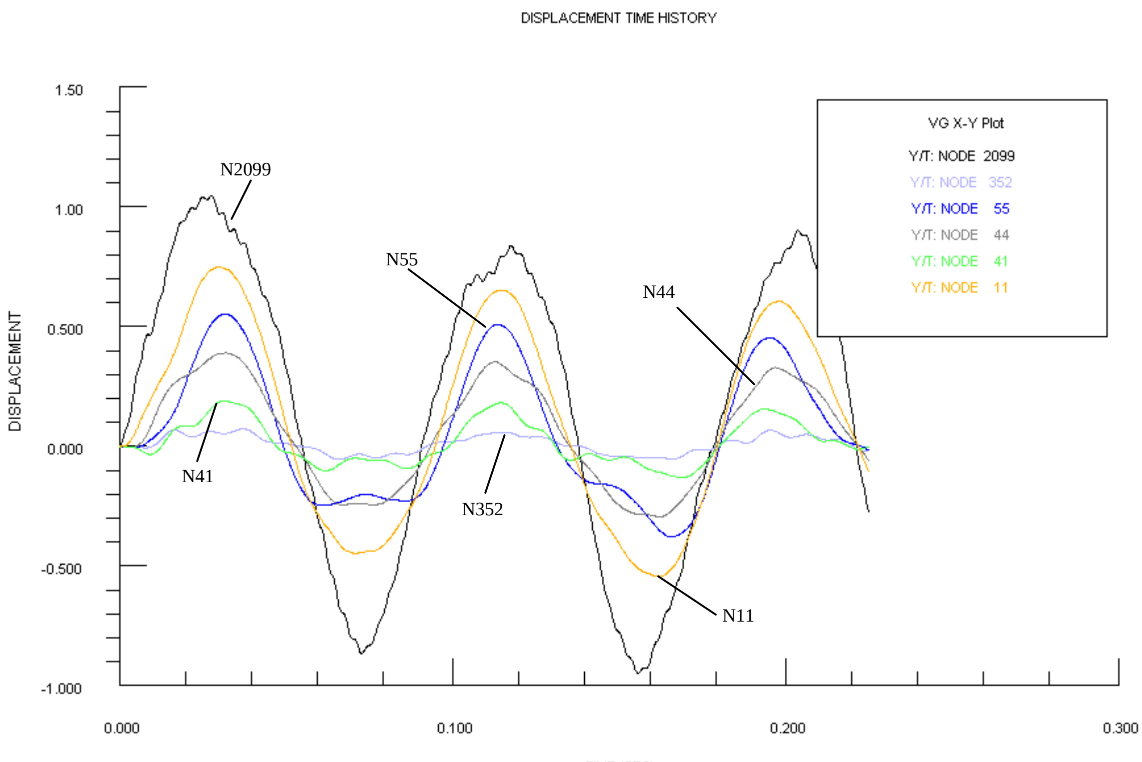



Figure 4.13: Time-displacement histories for model nodes of the Dicethrow Mast

**Table 4.6: Blast-induced dynamic strains (με) for the Dicethrow Mast**

| Member ID* | Description | Maximum Strain (με) | | |
|---|---|---|---|---|
| | | MASTSAS* | Norwood (1977) | |
| | | | Measured | Predicted |
| 2-10 | (E733) Forward-starboard leg of main trunk (1st bay) | +570.7 | +412.0 | +521.0 |
| 3-11 | (E750) Forward-port leg of main trunk (1st bay) | -432.5 | -490.0 | -512.0 |
| 9-16 | (E1011) Aft-starboard leg of main trunk (2nd bay) | +366.3 | +461.0 | +469.0 |
| 11-18 | (E1053) Aft-port leg of main trunk (2nd bay) | -381.4 | -441.0 | -470.0 |
| 17-24 | (E1320) Forward-starboard leg of main trunk (3rd bay) | +380.5 | +338.0 | +320.0 |
| 18-25 | (E1340) Forward-port leg of main trunk (3rd bay) | -260.2 | -322.0 | -320.0 |
| 25-32 | (E1591) Forward-port leg of main trunk (4th bay) | -246.8 | -234.0 | -223.0 |
| 32-29 | (E1418) Diagonal brace on fwd face of main trunk (4th bay) | +323.3 | +366.0 | +406.0 |
| 10-7 | (E504) Diagonal brace on fwd face of main trunk (1st bay) | -270.1 | -306.0 | -320.0 |
| 31-34 | (E2044) Horizontal brace at 4th (vertical) cross section | +170.1 | +164.0 | +191.0 |

*-Members are identified in terms of their associated endpoints (see Appendix A for illustrations showing endpoint node identification)

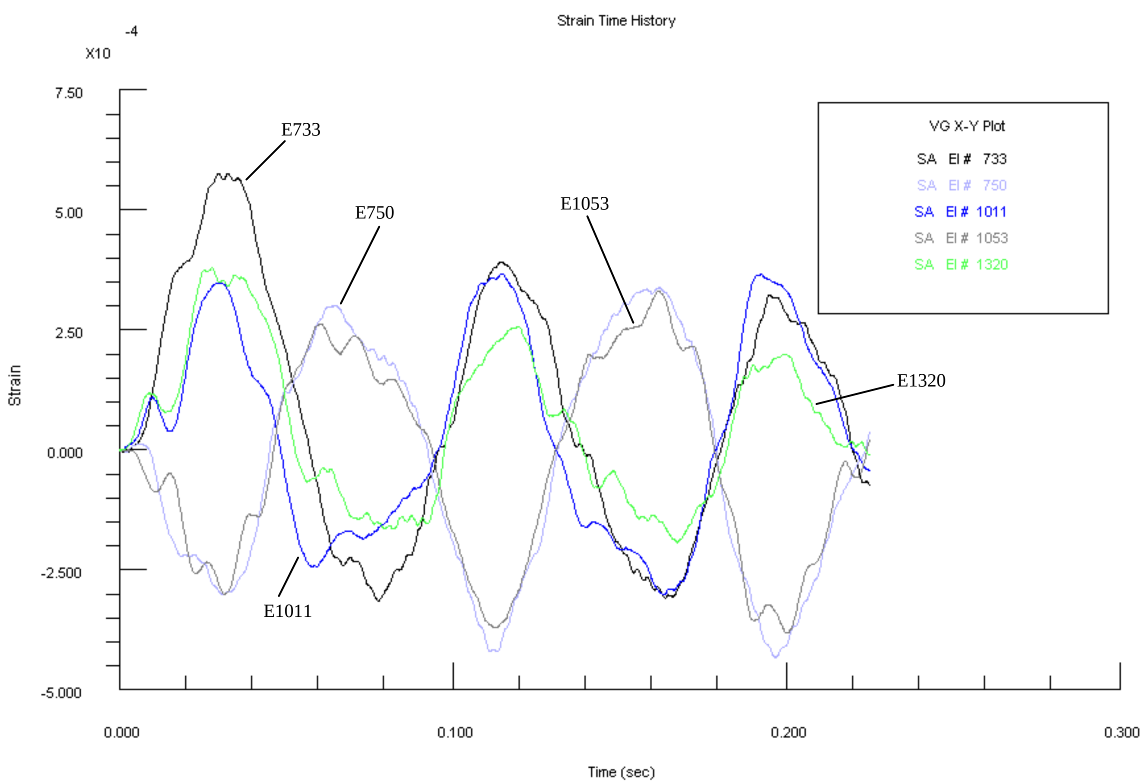



**Figure 4.14: Time-strain histories for model nodes of the Dicethrow Mast**

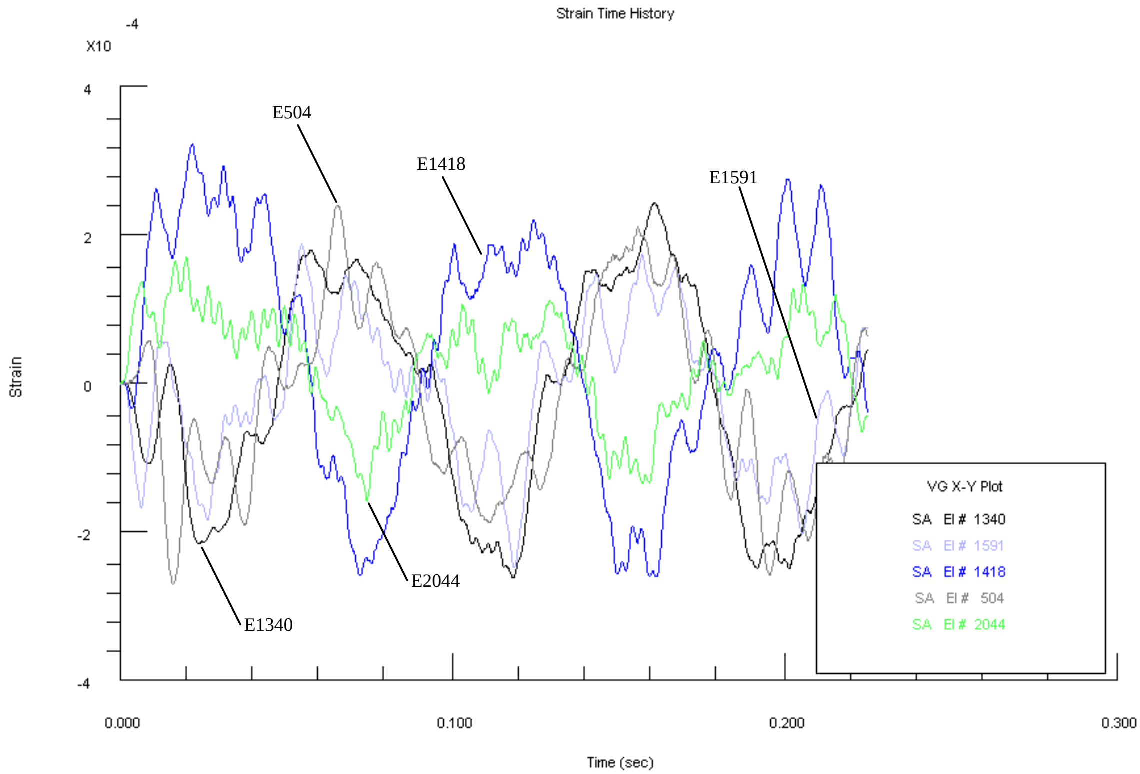



**Figure 4.14: Time-strain histories for model nodes of the Dicethrow Mast (cont.)**

### 4.4.4 Wind Loading

For demonstration purposes, the applied loading in this case was a 30-knot starboard wind (i.e., approaching from starboard). An air density of $1.125 \times 10^{-7}$ $lbs^2/in^4$ was specified for this analysis. Application of the wind loads via the MASTSAS interface is shown in Figure 4.15, while the applied loading is shown in Figure 4.16. The resulting displacement contours are presented in Figures 4.14 and 4.15. The maximum resultant wind-induced displacement (3.58in) was observed at the top/forward corner of the antenna plate, with components of 0.11in, 3.57in, and 0.24in in the longitudinal, athwartship and vertical directions, respectively. Figure 4.19(a), (b), and (c) illustrate the stress contours resulting from the applied wind loading. With a yield stress of 58ksi for most mast members, the stress contours suggest that the mast is adequate to support the loads from this 30-knot wind. A maximum compressive axial stress of –43.3 ksi was predicted for the aft/port main mast leg in the first bay (e.g., element 297). A comparable maximum tensile axial stress of +41.7 ksi was found in the aft/starboard main mast leg in the first bay (element 274). A maximum compressive flexural stress of –45.7 ksi was computed for element 304 located on the aft/port main mast leg in the first bay. The maximum tensile stress (47.3 ksi) was found in element 277, located in the aft/starboard main mast leg. Von Mises stresses in the antenna plate suggest a maximum stress of 2.26 ksi in element 1, well below the yield stress of 43.5ksi.

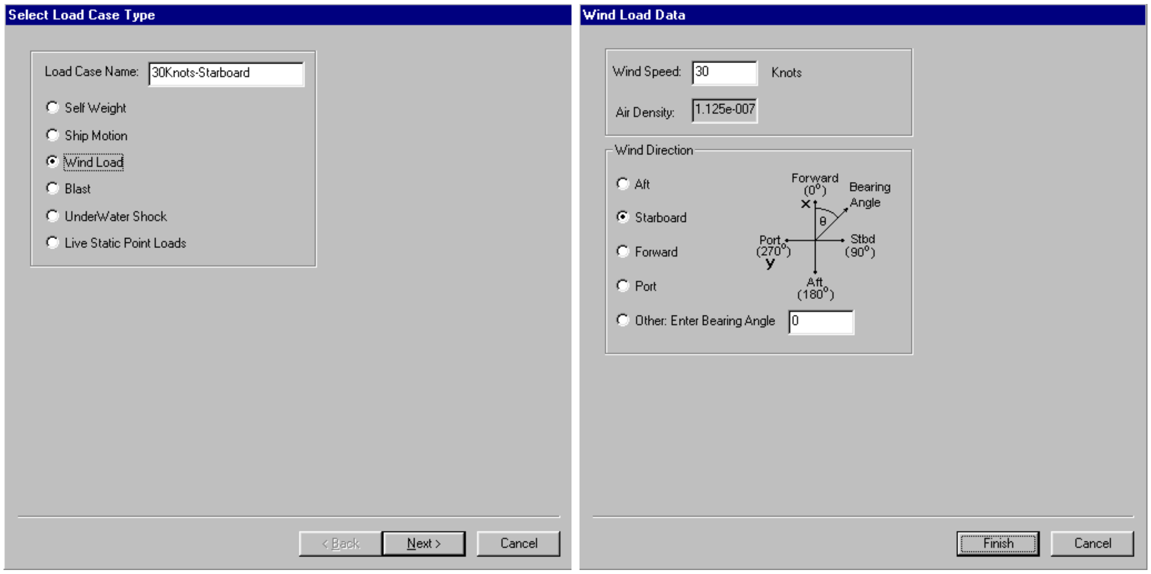



**Figure 4.15: Application of 30-knot starboard wind load**

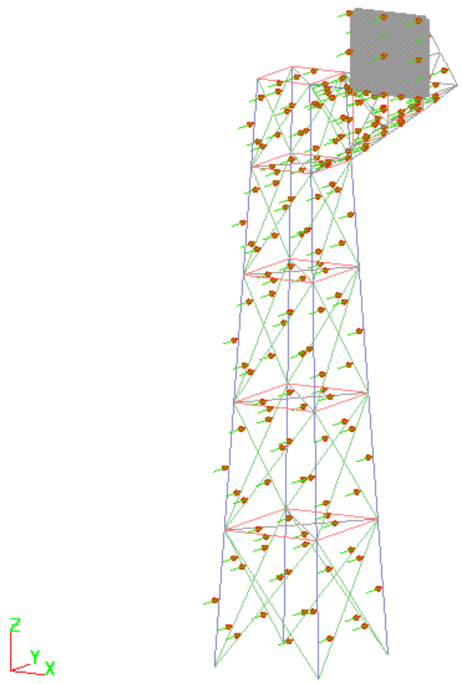


**Figure 4.16: 30-Knot starboard wind loading applied to Dicethrow Mast**

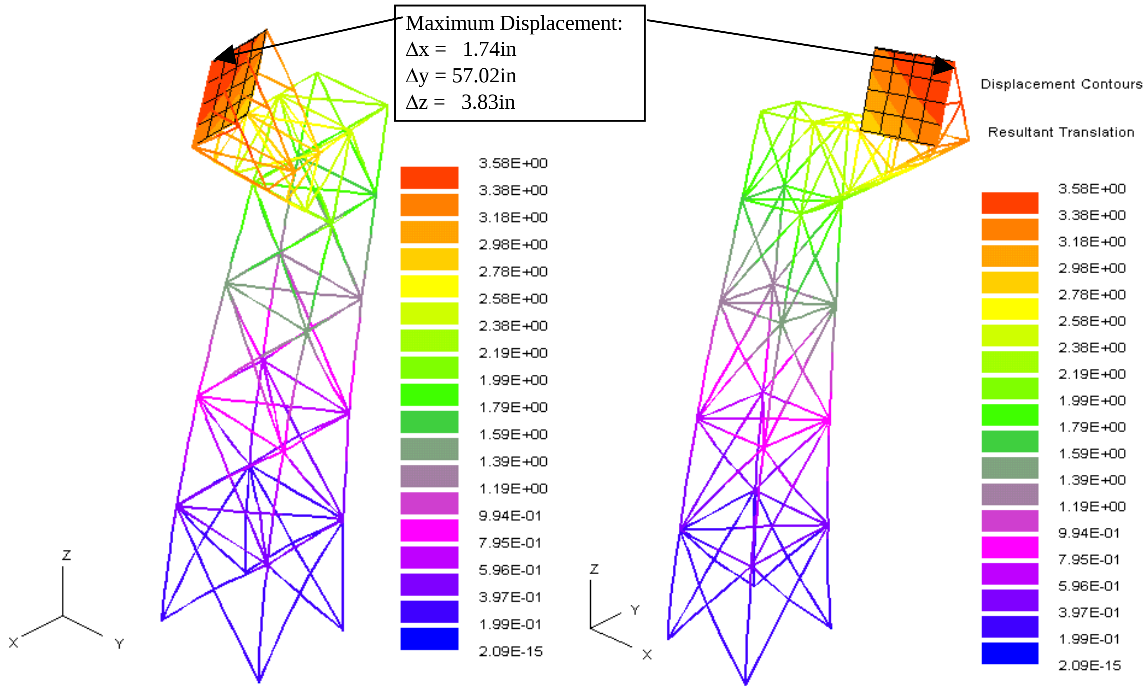



**Figure 4.17: Dicethrow Mast displacement contours resulting from 30-knot starboard wind**

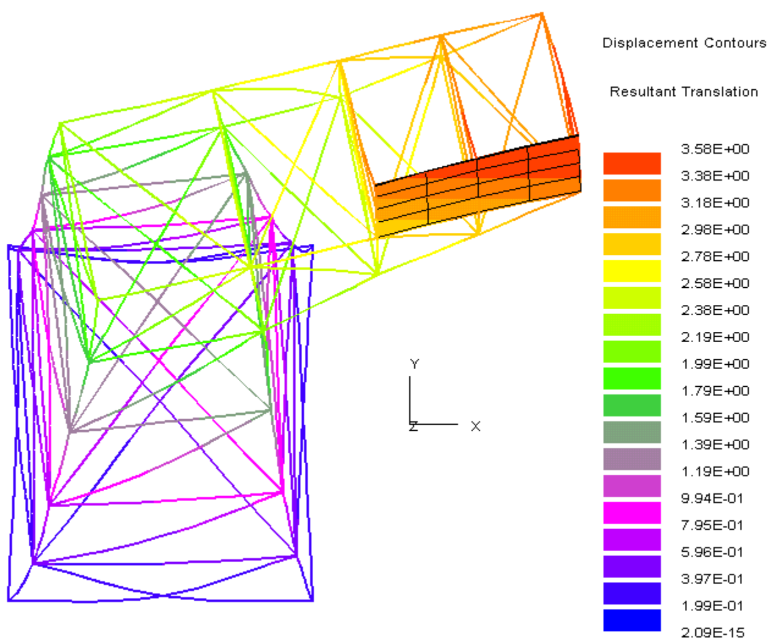



**Figure 4.18: Displacement contours showing twisting of Dicethrow mast**

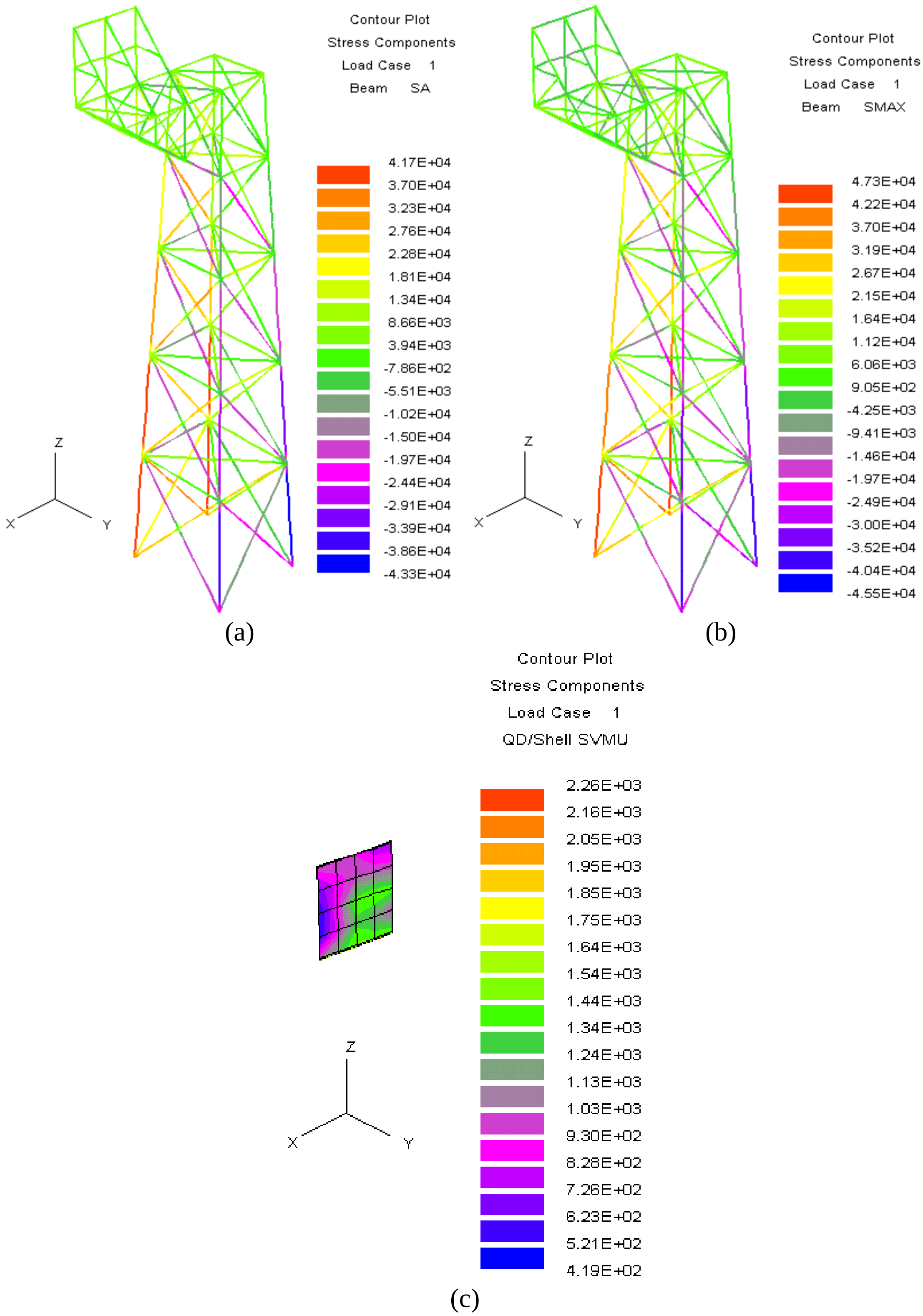



**Figure 4.19: Stress contours resulting from 30-knot starboard wind (a) axial stresses, (b) maximum stresses, and (c) von Mises stresses in antenna plate**

### 4.4.5 Ship Motion

This section outlines the response of the Dicethrow mast when subjected to ship motion. A ship motion analysis is meant to simulate the rigid body motion of a vessel (or one of its components) as it responds to wave conditions. The response depends not only on the characteristics of the incident waves (defined in terms of a 'sea state'), but also on vessel-related factors such as mass, dimensions, speed, and heading. The analysis is typically carried out using the base acceleration method (BAM), in which ship motion loads are described in terms of six acceleration components. Three translational acceleration components are applied at the center of gravity of the vessel (or mast in this case), while three rotational accelerations are applied at some specified center of rotation which may or may not coincide with the center of gravity of the mast structure. These acceleration components are generally used to describe a given 'sea state'. The six components are typically referred to as

- Surge (translational acceleration in the longitudinal direction);
- Sway (translational acceleration in the athwartship direction);
- Heave (translational acceleration in the vertical or draft direction);
- Pitch (rotational acceleration about the lateral axis of the vessel);
- Roll (rotational acceleration about the longitudinal axis of the vessel); and
- Yaw (rotational acceleration about the vertical axis of the vessel).

The worst-case loading condition for a vessel is assumed to arise while navigating in a sea state 5 (SS5), traveling at 26 knots, heading 120°, with 40° roll and 10° pitch. The corresponding acceleration components are

- Surge = 98.228 in/s$^2$ (x-direction in MASTSAS)
- Sway = 414.606 in/s$^2$ (y-direction in MASTSAS)
- Heave = 410.827 in/s$^2$ (z-direction in MASTSAS)
- Pitch = 0.0890 rad/s$^2$ (y-axis in MASTSAS)
- Roll = -0.0815 rad/s$^2$ (x-axis in MASTSAS)
- Yaw = -0.0545 rad/s$^2$ (z-axis in MASTSAS)

Application of these ship motions is illustrated in Figure 4.20 below. The resulting displacement contours are shown in Figure 4.21. As before, the maximum displacement (approximately 0.24in) is observed at the top/forward corner of the antenna plate. The corresponding axial and von Mises stress contours presented in Figure 4.22 suggest that yielding is unlikely.

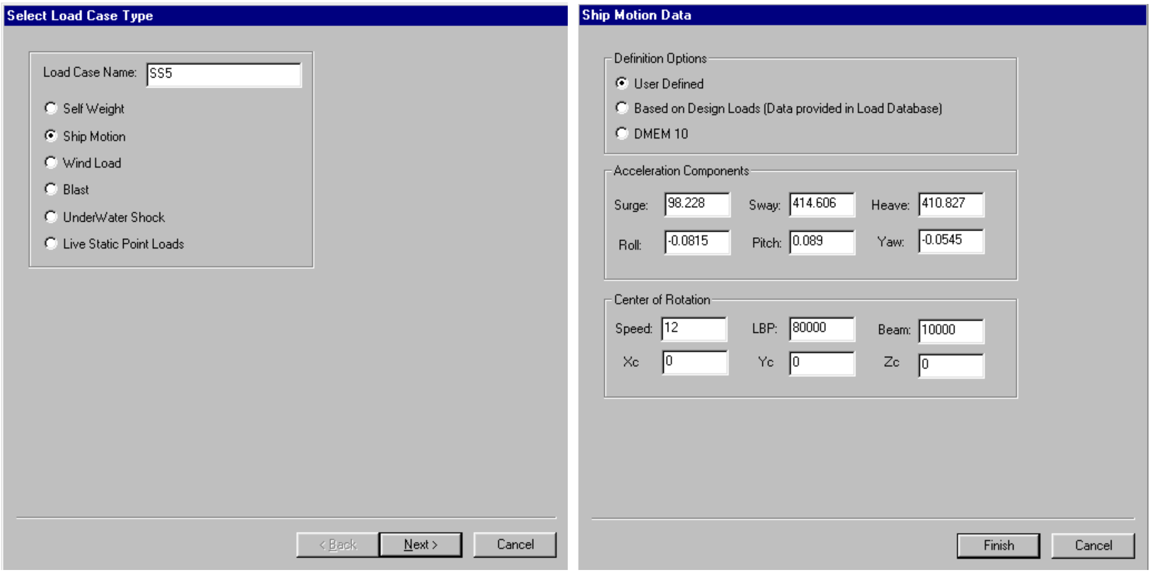



**Figure 4.20: Application of sea state 5 ship motion loads**

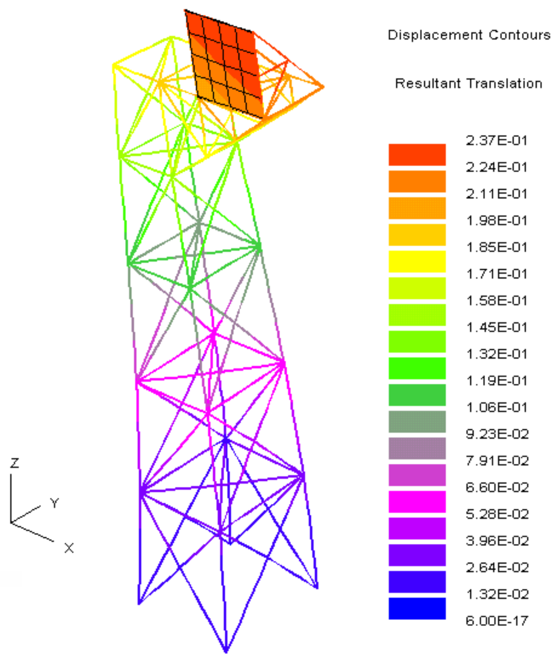



**Figure 4.21: Displacement contours under sea state 5 ship motions**

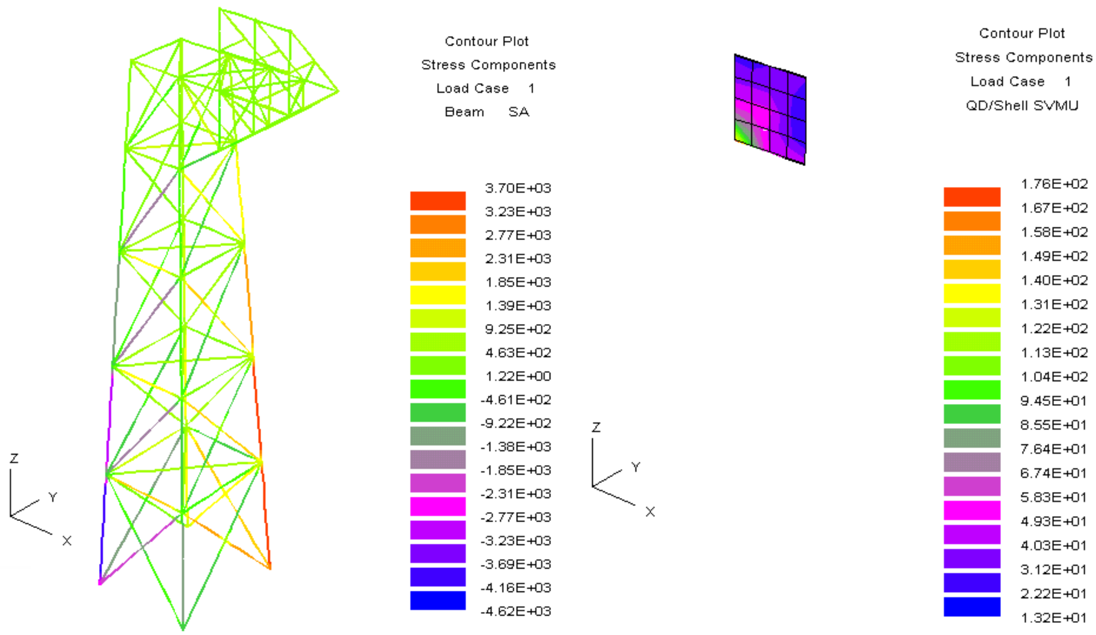



**Figure 4.22: Stress contours resulting from sea state 5 ship motion (a) axial stresses in main mast/yardarm structure and (b) von Mises stresses in antenna plate**

# 5. MODELING AND ANALYSIS OF THE CPF LATTICE MAST (EXAMPLE 4)

## 5.1 Problem Description

The Canadian Patrol Frigate (CPF) Mast was selected to illustrate the ability of the MASTSAS software to model configurations representative of those employed by the Canadian Navy. The CPF Mast structure is a highly complex mast configuration involving challenges including corner-attached yardarms, unusual lattice bay type sequences, stiffened panel configurations, and detailed bracing arrangements. Details of the mast configuration were obtained via a set of unclassified DND working drawings (CPF#8455596 (1-7)). The integrity of the software's modeling and analysis capabilities has been rigorously tested during its application to this real-life mast structure, leading to significant improvements to its functionality, robustness, and user-friendliness.

## 5.2 Notable MASTSAS Features

For some brace connection configurations, the algorithms currently available may not accurately size the gussets automatically. An option has therefore been implemented to allow the user to define a gusset size (area) to which suspect gussets may default. The user can predefine this adjusted area using the *Gusset Settings* menu (see Figure 5.1). When a mast is created, the user is further notified of the number of gussets requiring this default or adjusted area, as shown in Figure 5.2. To provide the user with graphical feedback (see Figure 5.3), gussets that cannot be sized automatically will be highlighted in pink, while those sized properly are shown in yellow. For situations where the default gusset size is not appropriate, users still have the option of manually setting the size of individual gussets using the tools provided in the gusset property page (see Figure 5.4).

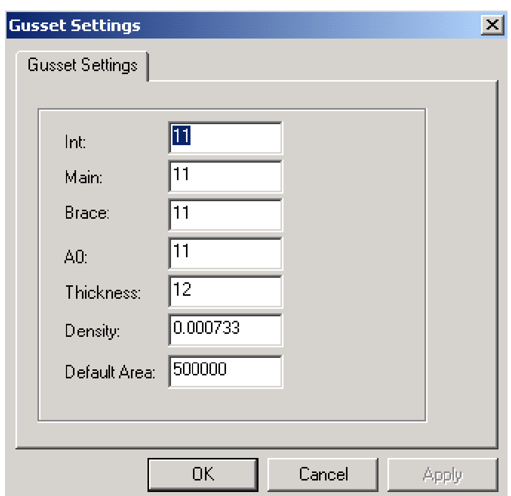



**Figure 5.1: Default gusset size defined in MASTSAS settings**

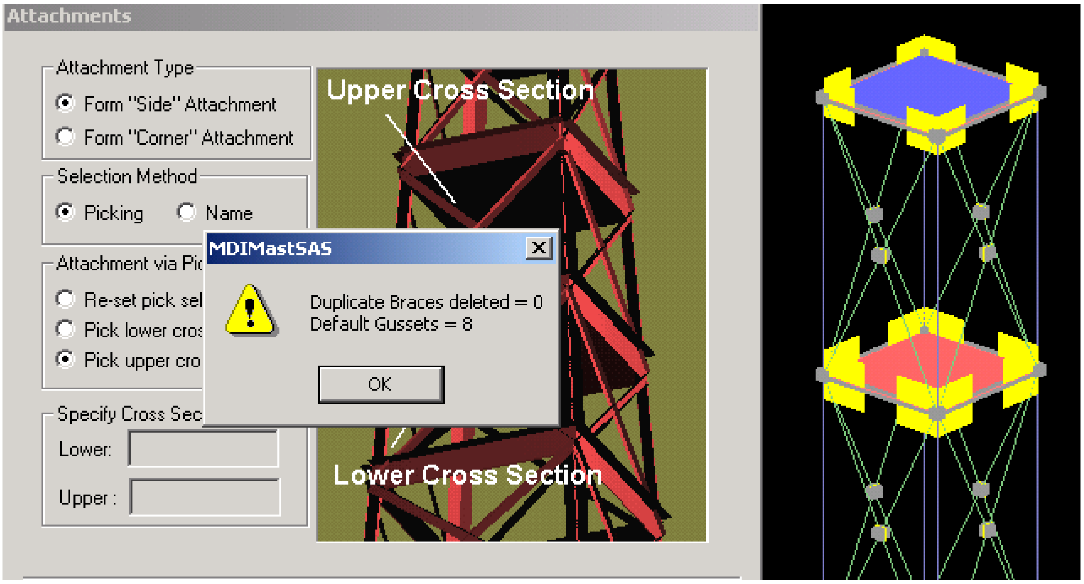



**Figure 5.2: User notification that default gusset size will be applied**

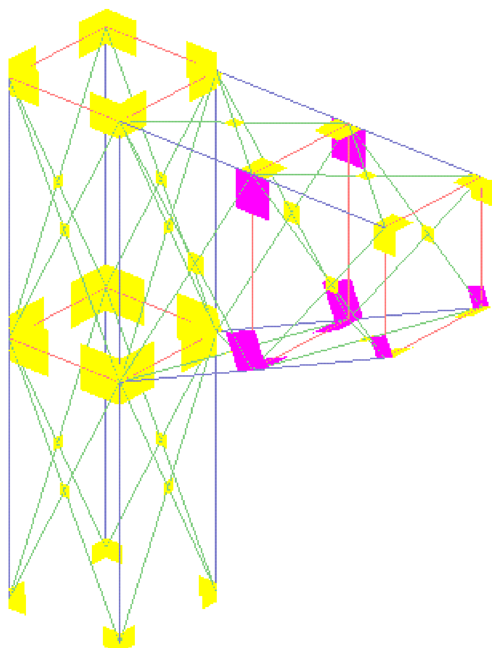


**Figure 5.3: Gussets requiring a predefined default/adjusted area highlighted in pink**

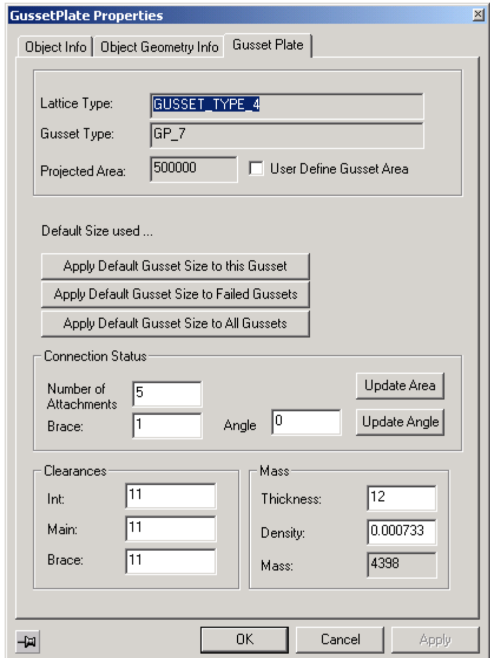



**Figure 5.4: Modifications to gussets property page**

The current version of MASTSAS also includes useful features such as:

- the ability to attach yardarms to mid-side trunk cross section nodes (where applicable) when attaching corner yardarms (see Figure 5.5)
- automatic deletion of braces having zero length due to cross section degeneration
- the ability to specify a vertical orientation for interpolated yardarm cross sections (see Figure 5.6) by double clicking on the desired cross-section and selecting the '*Make Vertical*' option from its property page.

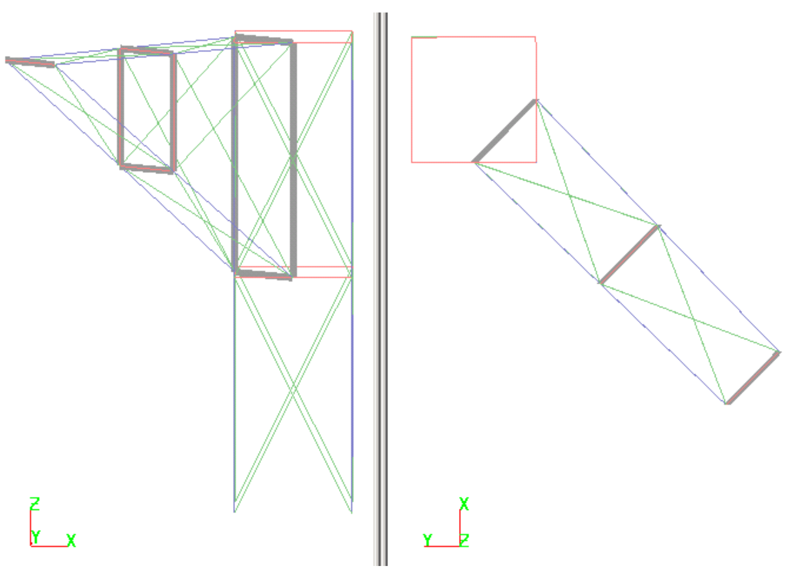



**Figure 5.5: Mid-side attachment of degenerated yardarm**

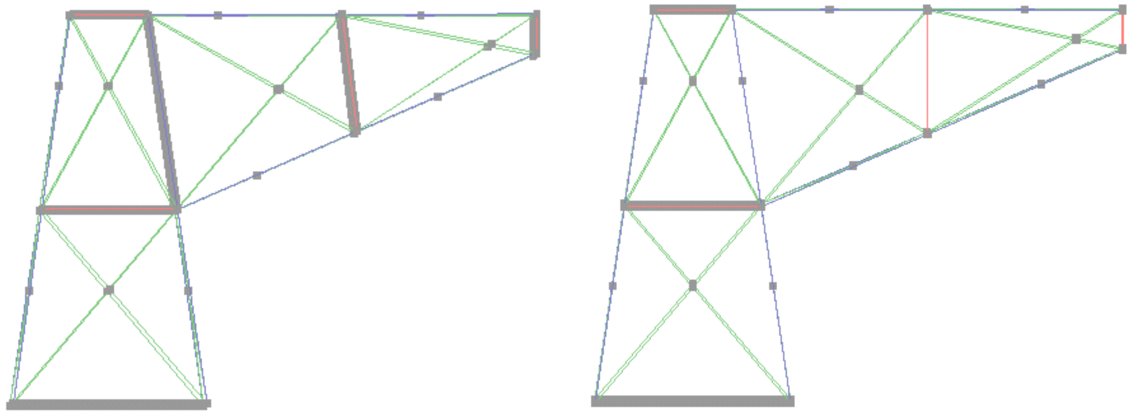

(a) (b)

**Figure 5.6: Vertical orientation of interpolated yardarm cross sections (a) before correction, and (b) after correction**

## 5.3 Model Development

Details of the mast configuration were obtained via a set of unclassified DND working drawings (CPF # 8455596 (1-7)). The material properties selected in developing this mast model were those of 350WT steel, E=207,000 MPa, $\nu$=0.30, $\rho$=7.85x10$^{-9}$ Ns$^2$/mm$^4$, and $\sigma_{yld}$=350 MPa.

### 5.3.1 Main Trunk

Cross-sectional dimensions for the various elevations comprising the main trunk of the structure are summarized in Table 5.1.

**Table 5.1: Summary of cross-sectional (CS) dimensions for main trunk of CPF Mast**

| CS No. | Identification | Elevation (mm) | Plan Dimensions | |
|---|---|---|---|---|
| | | | $\Delta$x (mm)[a] | $\Delta$y (mm)[b] |
| 1 | Deck 02 | 0 | 3729 | 5880 |
| 2 | Level A | 3300 | 2996 | 4537 |
| 3 | Level B | 5700 | 2470 | 3560 |
| 4 | Level C | 7700 | 2032 | 2746 |
| 5 | Level D | 9700 | 1594 | 1932 |
| 6 | **Level E** | 10900 | 1332 | 1444 |
| 7 | Level F | 11500 | 1200 | 1200 |

[a] – Fore/Aft direction
[b] – Port/Starboard direction

The main trunk of the CPF Mast was generated automatically using a combination of MASTSAS' lattice bay types C, D, and H. Appropriate diagonal and horizontal cross bracing members were then added/deleted as necessary to complete the main trunk. Moreover, the sizing of legs, horizontals, and diagonal bracing members (as well as the

orientation of some diagonal members) was found to vary throughout the main trunk, thus requiring that all brace settings be verified upon arriving at the final configuration.

### 5.3.2 Yardarms

Attachment of a number of yardarms was required throughout the main mast. Relevant details of each are discussed in the following paragraphs. Note that when defining mast yardarms, the term cross-section 'elevation' used here refers to the distance from the base cross-section.

***Corner Yardarm Between Levels C and D:***
A corner-attached yardarm was added to the model between Levels C and D. The base cross section of this yardarm was generated using the four mid-side nodes on the forward and port faces of the main trunk between Levels C and D. A baseline for subsequent cross section elevations was then defined by joining the Level D mid-side nodes of the base cross section. Based on the plan dimensions shown for Level D, this Level C-D yardarm was oriented off the forward-port corner at an angle of 37.716° (=$\tan^{-1}$ (2900mm/3750mm)) with the forward direction, with an overall yardarm length of 4400mm. The C-D yardarm is comprised of 5 cross-sections, defined as follows:

(i) CS#1: Level 0 (Base), Elevation = 0mm ($\Delta x \approx 1252$mm, $\Delta y \approx 2000$mm)
(ii) CS#2: Level 1 (Section KK), Elevation = 1625mm
(iii) CS#3: Level 2 (Section JJ), Elevation = 2725mm
(iv) CS#4: Level 3 (Section HH), Elevation = 3825mm
(v) CS#5: Level 4 (Section GG), Elevation = 4400mm ($\Delta x$=500mm, $\Delta y$=575mm)

The positions of all cross sections for this yardarm were measured with respect to the yardarm baseline at Level D. The plan dimensions of all intermediate cross sections were determined by interpolation. Each bay of the yardarm was generated using lattice bay type E. Additional braces were then added/deleted as necessary to produce the final yardarm configuration depicted by the working drawings. However, due to the configurations of the base and outer-most (i.e., 'top') cross-sections, the interpolated cross sections were originally oriented at some angle with the vertical direction. To overcome this limitation, a valuable feature was implemented into MASTSAS, allowing interpolated yardarm cross sections to be reoriented vertically. This feature was applied by first accessing the property page for each interpolated cross-section and selecting the '*Make Vertical*' option, and then redrawing the number of sub-divisions in the corresponding bay. Finally, the scantlings of all yardarm bracing were verified against those presented in the working drawings.

***Starboard Yardarm Between Levels D and F:***
A side-attached yardarm was then added off the starboard side of the model between Levels D and F. Based on the Level F side and plan views shown on the working drawings, the overall length of the yardarm was computed as 3500mm. The D-F yardarm is comprised of 5 cross-sections, defined as follows:

(i) CS#1: Level 0 (Base), Elevation = 0mm ($\Delta x \approx 1200$mm, $\Delta y \approx 1800$mm)
(ii) CS#2: Level 1, Elevation = 1150mm
(iii) CS#3: Level 2 (Section UU), Elevation = 2025mm
(iv) CS#4: Level 3 (Section TT), Elevation = 2900mm
(v) CS#5: Level 4 (Section SS), Elevation = 3500mm ($\Delta x$=600mm, $\Delta y$=325mm)

Positions of all cross-sections were measured with respect to the yardarm baseline at Level F. The plan dimensions of all intermediate cross sections were determined by interpolation. Each bay of the D-F starboard yardarm was initially generated using lattice bay type E. Additional braces were then added/deleted as necessary to produce the final yardarm configuration. Again, due to the configurations of the base and outer cross-sections, the interpolated cross sections were initially oriented at an angle to the vertical direction. As such, MASTSAS' '*Make Vertical*' feature was applied to vertically realign the interpolated cross sections. The scantlings of all bracing members were then verified to comply with those depicted in the working drawings.

***Forward, Port, and Aft Yardarms Between Levels E and F:***
A series of three yardarms were then attached off the forward, port, and aft faces of the mast between Levels E and F. These will serve as a framework on which to attach the complicated 'cage' structure between Levels E and F. The forward-facing E-F yardarm measures 1400mm in length, 1200mm in width, and 600mm in height, and is comprised of two equally spaced bays. The port-facing E-F yardarm measures 1150mm in length, 1200mm in width, and 600mm in height, also comprised of two equally spaced bays. Finally, the aft-facing E-F yardarm measures 3400mm in length, 1200mm in width, and 600mm in height, comprised of six cross sections at elevations of 0mm, 650mm, 1300mm, 1800mm, 2600mm, and 3400mm. All three yardarms were generated using lattice bay type H. Additional braces were added to each yardarm as necessary to achieve the final configuration.

### 5.3.3 'Cage' Structure

The remainder of the cage structure between Levels E and F was completed by specifying major nodes throughout each of its four quadrants. The major nodes required to complete the cage structure between Levels E and F are shown in Figure 5.7, while their associated nodal co-ordinates are summarized in Table 5.2. Member sizing and orientation were verified against the CPF mast working drawings. Note that the bracing configuration between Levels E and F was symmetric about the x-axis (i.e., the forward/aft direction).

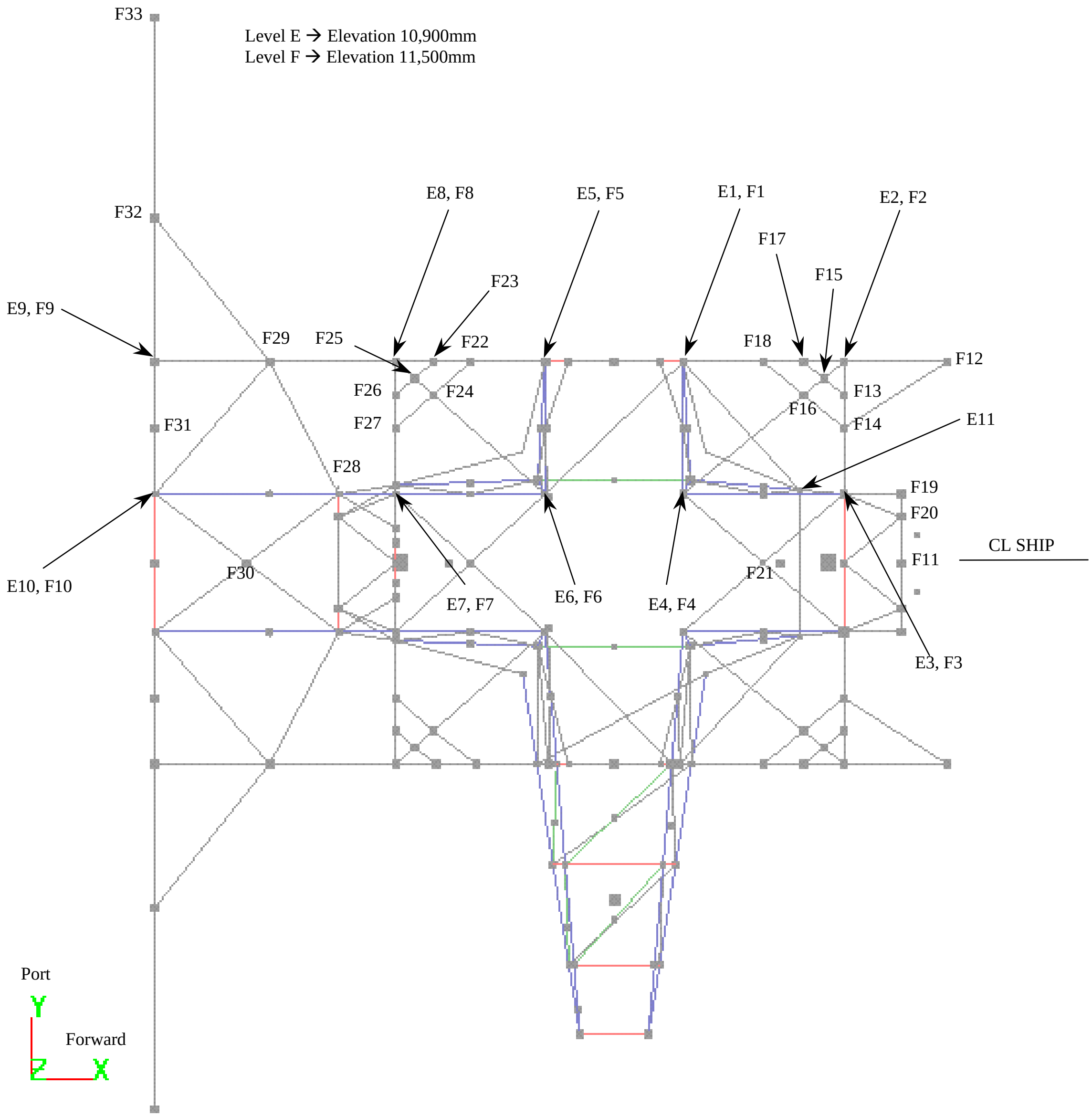



**Figure 5.7: Cage structure between Levels E and F of the CPF Mast**

**Table 5.2: Nodal points selected to model cage structure between Levels E and F**

| Node ID | Description | X Coordinate (mm) | Y Coordinate (mm) |
|---|---|---|---|
| E1, F1 | Outer forward corner of portside yardarm | 600 | 1750 |
| E2, F2 | Fwd/Port corner of cage structure | 2000 | 1750 |
| E3 | Outer portside corner of forward yardarm | 2000 | 722 |
| F3 | Outer portside corner of forward yardarm | 2000 | 600 |
| E4 | Inner forward corner of portside yardarm | 666 | 722 |
| F4 | Inner forward corner of portside yardarm | 600 | 600 |
| E5, F5 | Outer aft corner of portside yardarm | -600 | 1750 |
| E6 | Inner aft corner of portside yardarm | -666 | 722 |
| F6 | Inner aft corner of portside yardarm | -600 | 600 |
| E7 | Outer portside corner of aft yardarm | -1900 | 666 |
| F7 | Outer portside corner of aft yardarm | -1900 | 600 |
| E8, F8 | Aft/Port corner of cage structure | -1900 | 1750 |
| E9, F9 | Aft edge of cage structure | -4000 | 1750 |
| E10, F10 | Aft edge of cage structure | -4000 | 600 |
| E11 | Lower portside edge of forward yardarm | 1615 | 722 |
| F11 | Forward edge of cage structure @ CL ship | 2500 | 0 |
| F12 | Fwd/Port corner of cage structure | 2900 | 1750 |
| F13 | Member joining F2 & F3 split @ 25% | 2000 | 1462.5 |
| F14 | Member joining F2 & F3 split @ 50% | 2000 | 1175 |
| F15 | Member joining F2 & F4 split @ 12.5% | 1825 | 1606.25 |
| F16 | Member joining F2 & F4 split @ 12% | 1650 | 1462.5 |
| F17 | Member joining F1 & F2 split @ 75% | 1650 | 1750 |
| F18 | Member joining F1 & F2 split @ 50% | 1300 | 1750 |
| F19 | Forward edge of cage structure | 2500 | 600 |
| F20 | Forward edge of cage structure | 2500 | 400 |
| F21 | Forward yardarm @ CL ship | 1300 | 0 |
| F22 | Member joining F5 & F8 split @ 50% | -1250 | 1750 |
| F23 | Member joining F5 & F8 split @ 75% | -1575 | 1750 |
| F24 | Member joining F6 & F8 split @ 75% | -1575 | 1462.5 |
| F25 | Member joining F6 & F8 split @ 87.5% | -1737.5 | 1606.25 |
| F26 | Member joining F7 & F8 split @ 75% | -1900 | 1462.5 |
| F27 | Member joining F7 & F8 split @ 50% | -1900 | 1175 |
| F28 | Interior node of cage structure | -2400 | 600 |
| F29 | Aft/portside edge of cage structure | -3000 | 1750 |
| F30 | Aft yardarm @ CL ship | -3200 | 0 |
| F31 | Aft edge of cage structure | -4000 | 1175 |
| F32 | Aft edge of cage structure | -4000 | 3000 |
| F33 | Aft/Portside corner of cage structure | -4000 | 4750 |

Level E @ 10900mm, Level F @ 11500mm; CL = centerline

### 5.3.4 ECM Assemblies

After completing the cage structure between Levels E and F, the framing structures for housing the ECM assemblies were added to the forward half of the port and starboard faces of the main mast between Levels A and B. These brace assemblies could not be created using MASTSAS' automated features, but rather had to be constructed by inserting individual braces between key node points. Once the geometry was created for the starboard side assembly, symmetry about the x-axis (i.e., the forward-aft direction)

was used to quickly generate the nodal points required for the portside assembly. The sizing and orientation of structural members were verified against those presented in the CPF working drawings. The resulting ECM assembly is shown in Figure 5.8. The nodal coordinates for the selected points shown in Figure 5.8 are summarized in Table 5.3.

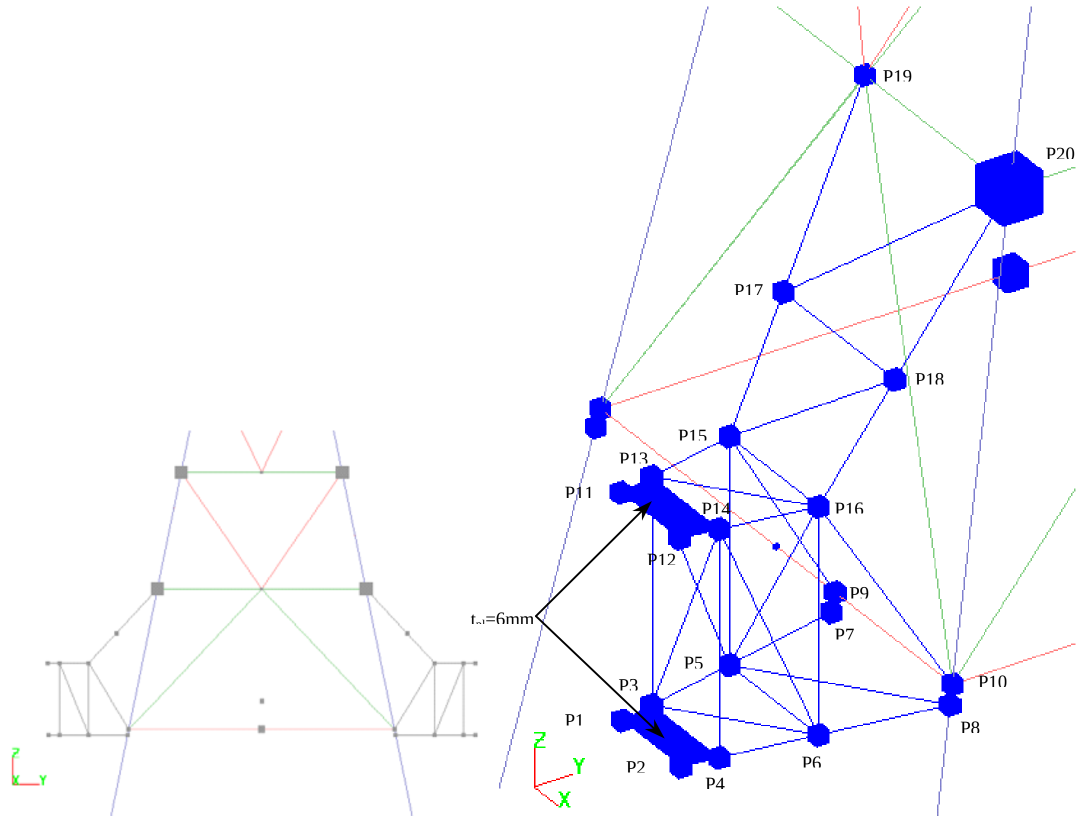


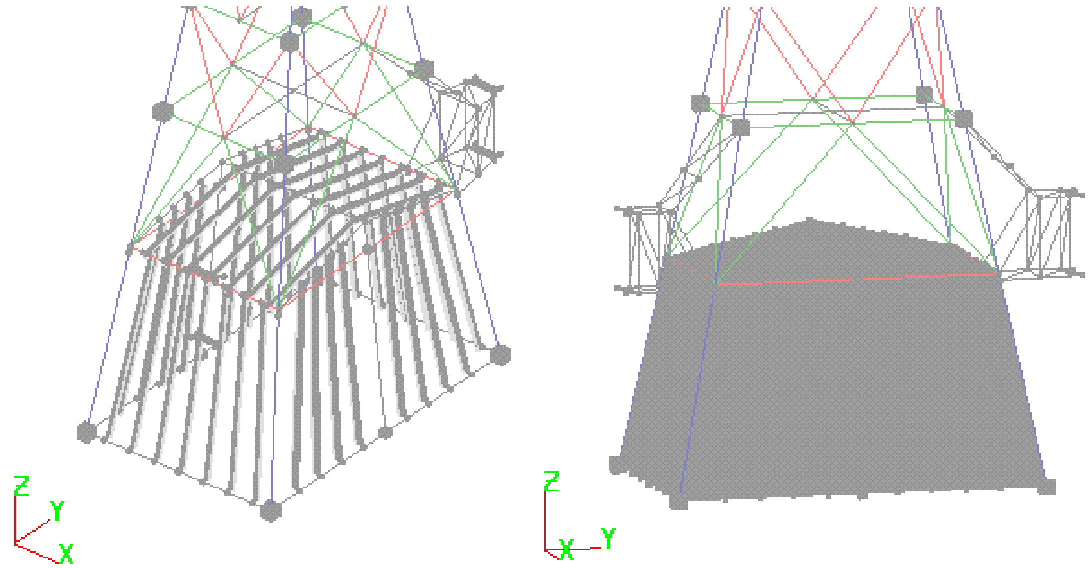

**Figure 5.8: Structural configuration for ECM assembly framing between Levels A and B**

**Table 5.3: Nodal coordinates of points selected to create ECM assembly framing**

| Node ID | X Coordinate (mm) | Y Coordinate (mm) | Z Coordinate (mm) |
|---|---|---|---|
| P1 | 800.00 | -3642.00 | 3200.00 |
| P2 | 1300.00 | -3642.00 | 3200.00 |
| P3 | 757.43 | -3450.00 | 3200.00 |
| P4 | 1329.67 | -3450.00 | 3200.00 |
| P5 | 646.58 | -2950.00 | 3200.00 |
| P6 | 1406.94 | -2950.00 | 3200.00 |
| P7 | 500.00 | -2288.85 | 3200.00 |
| P8 | 1509.11 | -2288.85 | 3200.00 |
| P9 | 500.00 | -2268.50 | 3300.00 |
| P10 | 1498.00 | -2268.50 | 3300.00 |
| P11 | 800.00 | -3650.00 | 4440.00 |
| P12 | 1300.00 | -3650.00 | 4440.00 |
| P13 | 757.43 | -3450.00 | 4440.00 |
| P14 | 1329.67 | -3450.00 | 4440.00 |
| P15 | 646.58 | -2950.00 | 4440.00 |
| P16 | 1406.94 | -2950.00 | 4440.00 |
| P17 | 388.32 | -2482.68 | 4943.27 |
| P18 | 1338.26 | -2482.68 | 4943.27 |
| P19 | 0.00 | -1780.00 | 5700.00 |
| P20 | 1235.00 | -1780.00 | 5700.00 |

### 5.3.5 Stiffened Panels

A number of stiffened panels were then added to enclose the ECM compartment between Deck 02 and Level A. It should be noted that the top of the enclosure is cambered slightly in the port-starboard direction, such that the midside nodes on the fore and aft faces at Level A were raised from an elevation of 3300mm to 3790mm. These two points were then joined by a fabricated girder (220x8 web, 120x8 flange plate). Additional details concerning the stiffened panel configurations were obtained using the DND working drawings (CPF#8455596 (1-7)). Each stiffened panel was generated using MASTSAS' automated features. While both the port- and starboard-facing panels were stiffened (vertically) by 127x102T stiffeners, stiffener sections varied for the fore- and aft-facing panels. The forward-facing panel was stiffened by 152x102T sections, whereas the aft-facing panel was stiffened by 127x102T (center) and 127x70T (off-center) stiffeners. Finally, the top panels of the enclosure were stiffened by 127x70T sections. Stiffener scantlings were obtained from the Handbook of Steel Construction CSA-S16.1-94. Stiffener spacings and edge offsets were obtained from the working drawings for the CPF mast (CPF#8455596 (1-7)), with spacings of 500mm and 375mm being typical for the top-, port-, and starboard-facing panels, and spacings of 550mm being more common for the fore- and aft-facing panels. The resulting ECM compartment enclosure is shown in Figure 5.9.




(a) (b)

**Figure 5.9: Stiffened panel configuration for ECM compartment on CPF Mast (a) transparent view, and (b) solid view**

### 5.3.6 Pole Mast

The CPF pole mast (auxiliary mast) was attached to the forward facing 1200mm x 1400mm yardarm previously attached between Levels E and F. Additional cross bracing was added as necessary. Cross-sectional dimensions for the various elevations comprising the pole mast are presented in Table 5.4.

**Table 5.4: Summary of cross-sectional (CS) dimensions for pole mast of CPF Mast**

| CS No. | Identification | Elevation[c] (mm) | Plan Dimensions | |
|---|---|---|---|---|
| | | | $\Delta x$ (mm)[a] | $\Delta y$ (mm)[b] |
| 1 | Level F | 0 | 1400 | 1200 |
| 2 | Level G | 1100 | 1210 | 1050 |
| 3 | Level H | 2000 | 1054 | 927.2 |
| 4 | Level J | 2900 | 899 | 804.6 |
| 5 | Level K | 3700 | 761 | 695.4 |
| 6 | Level K1 | 3950 | 717 | 661.4 |
| 7 | Level L | 4500 | 390 | 377.4 |
| 8 | Level L1 | 4650 | 300 | 300 |
| 9 | Level M | 5050 | 300 | 300 |
| 10 | Level M1 | 5290 | 300 | 300 |

[a] – Fore/Aft direction
[b] – Port/Starboard direction
[c] – Measured with respect to 'base' elevation of auxiliary mast (Level F)

The pole mast was generated using a combination of MASTSAS' lattice bay type A. Appropriate diagonal and horizontal cross bracing were added/deleted as necessary to complete the auxiliary mast. As bracing member scantlings varied throughout the length

of the pole mast, all brace setting selections were verified upon arriving at the final pole mast configuration.

### 5.3.7 Equipment

The MASTSAS equipment database was modified to include CPF equipment. The mass and general location of this equipment is summarized in Table 5.5 below. MASTSAS permits the user to apply equipment directly or define appropriate nodal masses to simulate the equipment. In this example, nodal masses were added to the model based on the equipment locations noted in the CPF working drawings (CPF#8455596 (1-7)).

**Table 5.5: CPF Mast equipment (Smith (2003), Crocker et. al (1998))**

| Equipment Type | No. Units | Unit Wgt* ($Ns^2/m$) | Total Wgt* ($Ns^2/m$) | Location |
|---|---|---|---|---|
| UHF Polemast + TACAN (A) | 1 | 324 | 324 | Level N (Elev. 17,000mm) |
| Masthead Bite Box (Canews) (B) | 1 | 32 | 32 | Level F (Elev. 11,500mm) |
| Freq. Assem. Ant. (Omni-Canews) (C) | 1 | 14 | 14 | Level J (Elev. 14,400mm) |
| DF Assem. Ant. (Canews) (D) | 4 | 29 | 116 | Level F Cage (Elev. 11,500mm) |
| DF Assem. Ant. (O-Band Canews) (E) | 4 | 6 | 24 | Level F Cage (Elev. 11,500mm) |
| Surf. Search & Nav. Radar Ant. (F) | 1 | 54 | 54 | Level D (Elev. 9,700mm) |
| UHF Radio Omni-Directional Ant. (G) | 2 | 50 | 100 | Level F Stbd Yardarm (Elev. 11,500mm) |
| ECM Assem. Antenna (Ramses) (H) | 2 | 60 | 120 | Level A (Elev. ~3,790mm) |
| IFF Transponder Ant. (Omni) (J) | 1 | 6 | 6 | Level F Cage Wing (Elev. 11,500mm) |
| VHF/FM Maritime Mobile Ant. (K) | 2 | 1 | 2 | Level F Cage Wing (Elev. 11,500mm) |
| Navstar Antenna (L) | 1 | 55 | 55 | Level D (Elev. 9,700mm) |
| Light (M) | 1 | 5 | 5 | Level L (Elev. 16,000mm) |
| Wind Speed/Direction Detector (N) | 2 | 7 | 14 | Level F Cage Wing (Elev. 11,500mm) |
| Flashing Yardarm Light (P) | 2 | 5 | 10 | Level F Cage Wing (Elev. 11,500mm) |
| Sr. Officers Indication Light (Q) | 1 | 5 | 5 | Level L (Elev. 16,000mm) |
| Whip Tactical Portable Trans. Ant. (R) | 1 | 3 | 3 | Level A (Elev. ~3,790mm) |
| Centerline Light (S) | 1 | 3 | 3 | Level L (Elev. 16,000mm) |
| Fwd Steaming Masthead Light (T) | 1 | 5 | 5 | Level J (Elev. 14,400mm) |
| Radar/Surveill. Ant. (Sea Giraffe) (U) | 1 | 628 | 628 | Level G (Elev. 12,600mm) |
| Imped. Matching Network Ant. (V) | 1 | 39 | 39 | Level D (Elev. 9,700mm) |
| Halyard Signal Flags (AA) | 6 | 5 | 30 | Level F Cage Wing (Elev. 11,500mm) |
| Electric Whistle (BB) | 2 | 100 | 200 | Level A (Elev. ~3300mm to 3,790mm) |
| SATCOM OE-82 Antenna (CC) | 2 | 179 | 358 | Deck 02 (Elev. ~ 0mm) |
| Helicopter Approach Light (DD) | 1 | 5 | 5 | Level D (Elev. 9,700mm) |
| | | **Total:** | **2152** | |

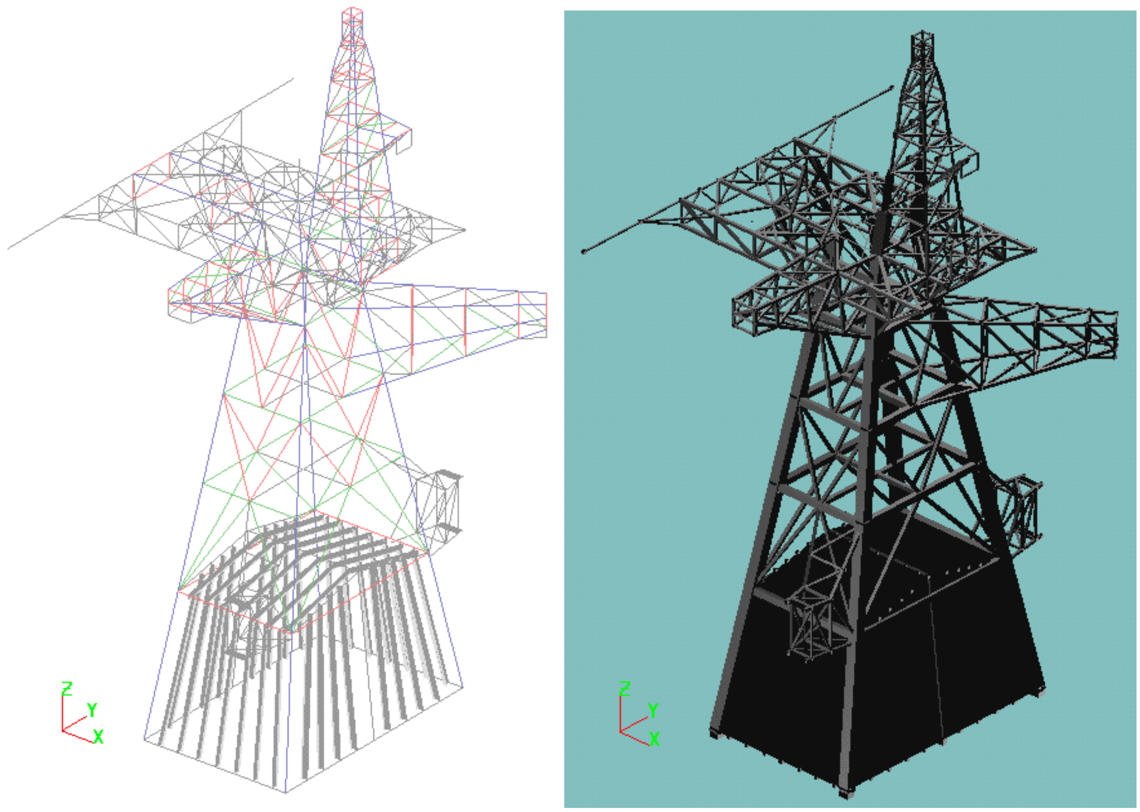
* - To arrive at consistent units of N and mm, divide by 1000 (1kg = $1Ns^2/1000mm$)

### 5.3.8 Final Configuration

The resulting CPF Mast configuration is shown in Figure 5.10. Note that the figure on the right depicts the member sections in three dimensions. This is another valuable MASTSAS feature that allows the user to quickly identify members whose scantlings or

orientation may have been defined incorrectly.  To the best of our knowledge, such a feature is unavailable in conventional modeling packages.

Boundary conditions were then applied to the CPF mast structure, assuming the base to be completely restrained against both translation and rotation.  After specifying a default element size of approximately 150mm, a finite element mesh was generated using MASTSAS' automatic meshing feature.  The finite element model was then exported to a DSA database, which could then be used in conjunction with the VAST solver to perform a number of finite element analyses.




(a) (b)

**Figure 5.10: Final CPF Mast configuration showing (a) two-dimensional view of mast members, and (b) three-dimensional view of mast members**

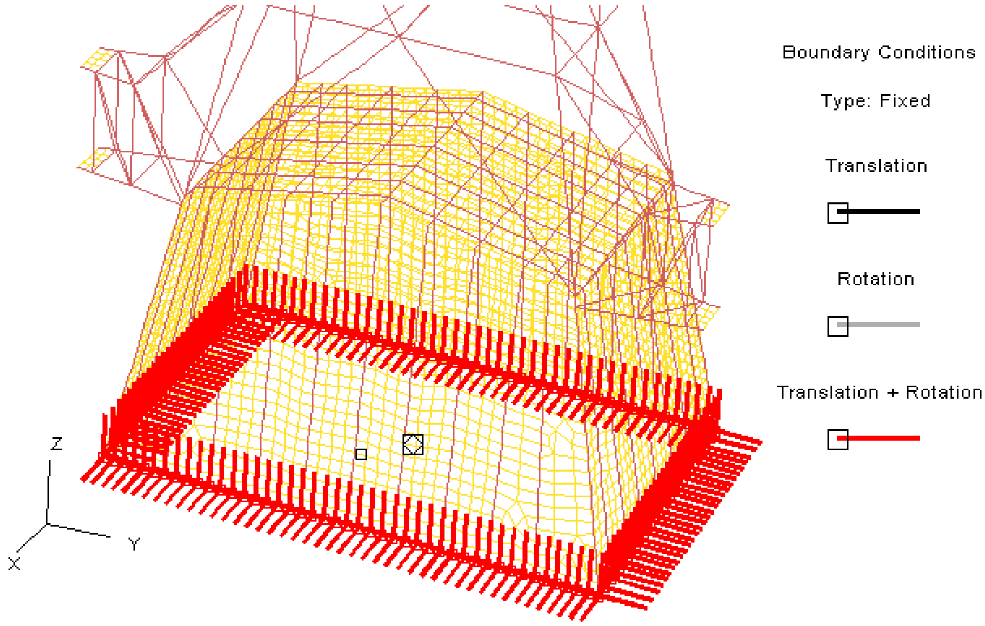



**Figure 5.11: Boundary conditions applied to CPF model**

## 5.4 Analysis

### 5.4.1 Eigenvalue Analysis

The first analysis performed on the CPF mast model was a natural frequency analysis. The analysis was carried out assuming a consistent mass matrix formulation and direct iteration, in conjunction with DSA's new sparse solver. The mass of the entire mast was computed as 13,174 kg (not including equipment), which is within 5% of that reported by others (Crocker et al., 1998). It should be noted that the access hole cut-outs throughout the main mast legs were not included in the MASTSAS model, resulting in an increase in both mass and stiffness over those reported by Crocker et al. (1998). The total mass of the equipment was computed as 2152kg, slightly larger than that reported by Crocker et al. This was due to fact that more complete equipment data was available.

The most significant vibration modes for the CPF are summarized in Table 5.6. Natural frequencies for the first thirty vibration modes are presented in Table 5.7. Also shown in these tables are the results presented by Crocker et al. (1998), in which natural frequencies were computed based on Martec's DSA software and an analysis performed by MIL Systems Engineering Inc. (MSEI, 1994), and those computed by YARD Incorporated (1988). The first four modes are considered invalid, as they indicate localized vibration response of the extreme ends or 'wings' of the aft-most section of the cage structure between Levels E and F.

The fifth mode (8.019 Hz) is considered to be the first significant longitudinal mode, while the eighth mode (11.336 Hz) is the first significant athwartship mode. The first significant vertical mode was the twenty-fourth mode (33.804 Hz). While these results compare well with the results reported by MSEI and Yard Inc., they differ from those

reported by Crocker et al. (1998). This is thought to be due in part to the increase in stiffness as a result of not including access hole cut-outs in the MASTSAS model's main mast legs, coupled with a small reduction in the mass of the overall mast used by Crocker et al. The highest modal participation factor for longitudinal vibration was found for mode 5 at 8.019 Hz, while that for athwartship vibration was observed for mode 11 at 18.17 Hz (only slightly greater than that found for mode 8 at 11.336 Hz). The highest modal participation factor for vertical vibration was observed for mode 24 at 33.804 Hz.

**Table 5.6: Comparison of Eigenvalue Responses for the CPF Mast**

| Description | MASTSAS Freq. (Hz) | DSA[1] Freq. (Hz) | MSEI[1] Freq (Hz) | YARD Inc. Freq. (Hz) |
|---|---|---|---|---|
| First Significant Longitudinal Mode | 8.019 | 5.673 | 8.709 | 8.640 |
| Second Significant Long. Mode | 15.378 | 10.465 | | 14.012 |
| First Significant Athwartship Mode | 11.336 | 6.692 | 11.996 | 11.617 |
| Second Significant Ath. Mode | 18.168 | 13.038 | | 15.024 |
| First Significant Vertical Mode | 33.804 | | | 28.034 |
| Second Largest Significant Vert. Mode | 38.938 | | | 44.820 |

1 - Results of natural frequency analysis reported by Crocker et al. (1998)

**Table 5.7: Natural frequencies (Hz) for the CPF Mast**

| Mode No. | MASTSAS | DSA* | MSEI* | YARD Inc. |
|---|---|---|---|---|
| 1 | 3.658 | 4.133 | 4.521 | 4.163 |
| 2 | 3.703 | 4.134 | 4.630 | 4.267 |
| 3 | 4.478 | 4.202 | 5.204 | 5.203 |
| 4 | 4.547 | 4.207 | 5.270 | 5.269 |
| 5 | [1,4] **8.019** | [1] **5.673** | 5.333 | 5.333 |
| 6 | 10.099 | [2] **6.692** | 5.343 | 5.342 |
| 7 | 11.178 | [4] **10.465** | [1,4] **8.709** | [1,4] **8.640** |
| 8 | [2] **11.336** | 11.544 | 10.501 | 10.521 |
| 9 | 13.055 | [5] **13.038** | 11.679 | [2,5] **11.617** |
| 10 | 15.378 | 16.853 | 11.716 | 14.012 |
| 11 | [5] **18.168** | 18.373 | [2,5] **11.996** | 15.024 |
| 12 | 19.365 | 20.016 | 14.772 | 17.401 |
| 13 | 24.197 | 21.749 | 15.593 | 19.596 |
| 14 | 26.299 | 22.234 | 19.670 | 22.667 |
| 15 | 26.651 | 24.325 | 19.921 | 23.224 |
| 16 | 26.656 | 25.539 | 23.170 | 24.970 |
| 17 | 27.078 | 25.975 | 25.020 | 26.082 |

* - Results of natural frequency analysis reported by Crocker et al. (1998)
1 – First significant longitudinal vibration mode; 2 – First significant athwartship vibration mode
3 – First significant vertical vibration mode; 4 – Highest modal participation factor (long.)
5 – Highest modal participation factor (ath.); 6 – Highest modal participation factor (vert.)

**Table 5.7: Natural frequencies (Hz) for the CPF Mast (cont.)**

| Mode No. | MASTSAS | DSA* | MSEI* | YARD Inc. |
|---|---|---|---|---|
| 18 | 28.440 | 26.982 | 25.696 | 27.495 |
| 19 | 29.308 | 28.338 | 26.527 | 28.034 |
| 20 | 29.733 | 28.929 | 28.819 | 29.593 |
| 21 | 29.792 | 28.969 | 29.472 | 32.659 |
| 22 | 30.695 | 29.242 | 31.160 | 34.287 |
| 23 | 30.760 | 29.352 | 32.739 | 37.046 |
| 24 | [3,6] **33.804** | 30.233 | 34.267 | 38.742 |
| 25 | 35.108 | 30.476 | 34.354 | 39.961 |
| 26 | 36.283 | 30.859 | 38.659 | 41.680 |
| 27 | 37.460 | 30.969 | 40.479 | [3,6] **44.820** |
| 28 | 37.572 | 31.684 | 41.743 | 46.507 |
| 29 | 38.938 | 32.358 | 44.273 | 49.282 |
| 30 | 39.431 | 33.020 | 44.779 | 50.283 |

* - Results of natural frequency analysis reported by Crocker et al. (1998)
1 – First significant longitudinal vibration mode; 2 – First significant athwartship vibration mode
3 – First significant vertical vibration mode; 4 – Highest modal participation factor (long.)
5 – Highest modal participation factor (ath.); 6 – Highest modal participation factor (vert.)

### 5.4.2 Wind Loading Analysis

A 120-knot starboard wind is a commonly specified load case for analysis of mast structures, and will comprise the applied loading in this analysis. An air density of $1.205 \times 10^{-12}$ $Ns^2/mm^4$ was specified for the analysis. The applied wind loading is shown in Figure 5.12.

The resulting displacement contours are presented in Figure 5.13. A maximum displacement (resultant) of approximately 4.4 mm was observed at the top-most cross-section of the polemast. The contours of element stresses resulting from the applied wind loading are presented in Figure 5.14. The axial stresses presented in Figure 5.14 (a) suggest maximum tensile and compressive stresses of ±19.6 MPa in the diagonal cross-bracing on the forward face of the mast at Level B. The maximum stress plot of Figure 5.14 (b) indicates maximum flexural stresses of 37.1 MPa and –38.4 MPa in elements 5229 and 5234, respectively, both located near the center of the cage structure at Level F. The (upper) von Mises stresses shown in Figure 5.14 (c) suggest a maximum stress of 33.1 MPa in the plating at the forward/starboard corner of the ECM compartment. Clearly, all components of the mast are well below yield when subjected to the 120 knot starboard wind.

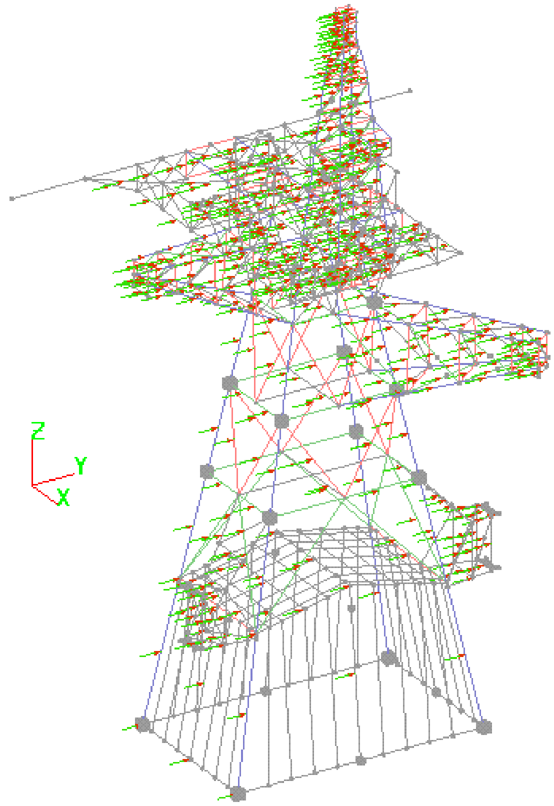



**Figure 5.12: 120-knot starboard wind applied to the CPF Mast**

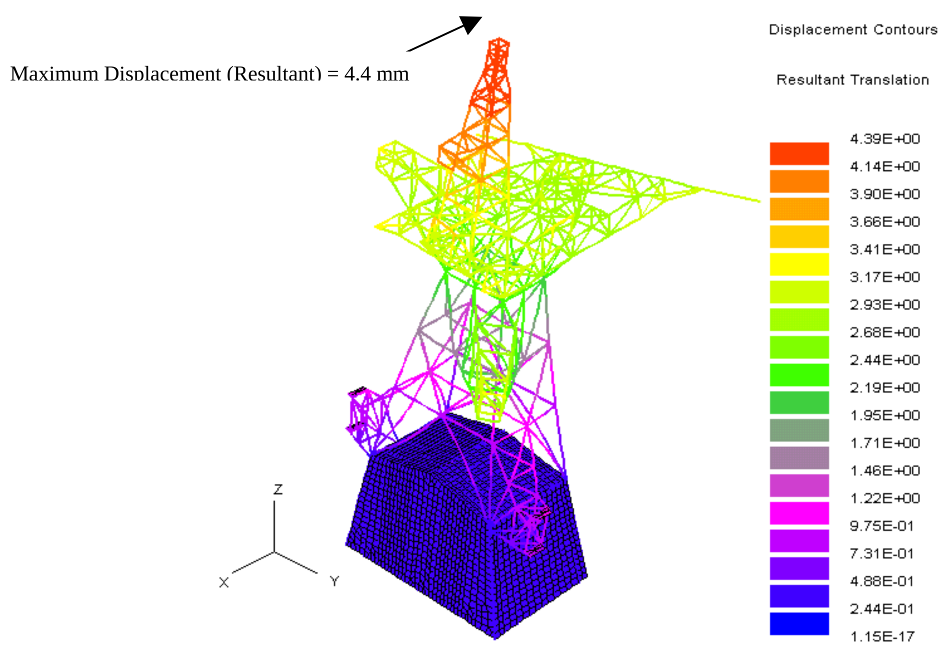
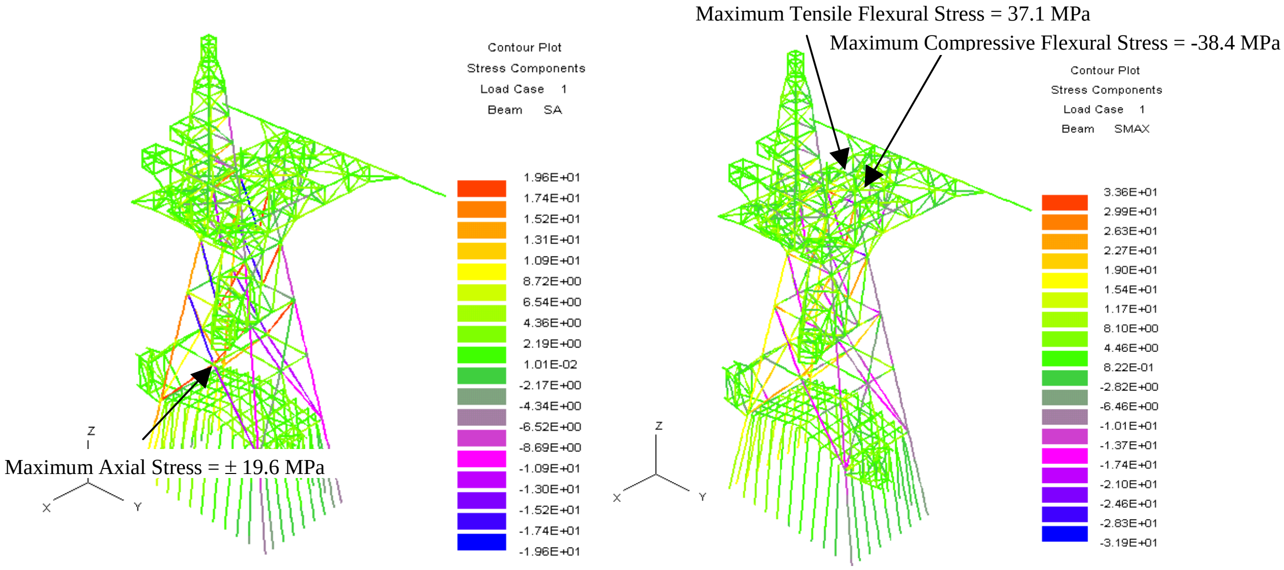
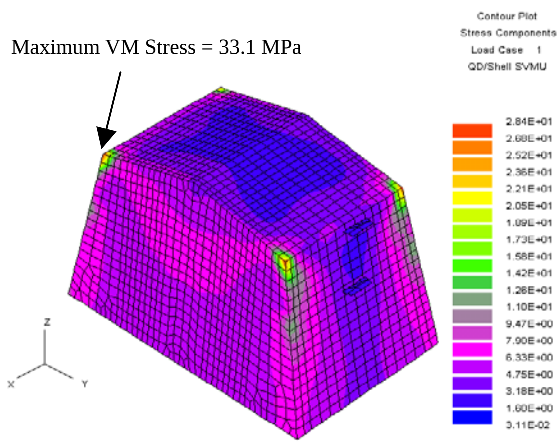



**Figure 5.13: Displacement contours resulting from 120-knot starboard wind applied to the CPF Mast**




(a) Axial stresses (b) Maximum stresses

**Figure 5.14: Stress contours resulting from 120-knot starboard wind applied to the CPF Mast**




(c) von Mises stresses (upper) in ECM compartment plating

**Figure 5.14: Stress contours resulting from 120-knot starboard wind applied to the CPF Mast(cont.)**

### 5.4.3 Ship Motion Analysis

As mentioned previously in section 4.4.5, a ship motion analysis simulates the rigid body motion of a vessel (or one of its components) as it responds to wave conditions from a given sea state. As discussed earlier, the worst-case loading condition for a vessel is generally referred to as sea state 5 (SS5), in which the vessel is assumed to be advancing at a speed of 26 knots, on a heading 120°, under 40° roll and 10° pitch. The corresponding acceleration components are:

- Surge = 2495 mm/s$^2$ (x-direction in MASTSAS)
- Sway = 10531 mm/s$^2$ (y-direction in MASTSAS)

- Heave = 10435 mm/s$^2$ (z-direction in MASTSAS)
- Pitch = 0.0890 rad/s$^2$ (y-axis in MASTSAS)
- Roll = -0.0815 rad/s$^2$ (x-axis in MASTSAS)
- Yaw = -0.0545 rad/s$^2$ (z-axis in MASTSAS)

The applied translational and rotational ship motions are illustrated in Figure 5.15.

The response of the extreme ends or 'wings' of the aft-edge of the cage structure between Levels E and F shows maximum displacements of $\Delta x$ = –24.0 mm (longitudinal), $\Delta y$ = -3.1 mm (lateral or athwartship), and $\Delta z$ = –22.4 mm (vertical or draft). For the main mast structure itself, the maximum longitudinal and athwartship displacements of –6.8 mm and –5.4 mm, respectively, are observed along the top-most aft edge of the polemast, while the maximum vertical displacement of –2.2 mm is found along the aft edge of the Level E-F cage. The associated displacement contours are shown in Figure 5.16. The stress contours representing mast members' axial stresses, illustrated in Figure 5.17(a), suggest a maximum stress (compressive) of -25.4 MPa for the starboard/aft main mast leg at Level A. The maximum stress plot of Figure 5.17(b) indicates a maximum compressive flexural stress of –196.2 MPa in element 6521, located near the extreme ends or 'wings' of the aft-edge of the cage structure between Levels E and F. A maximum tensile flexural stress of 56.6 MPa is observed for element 4772, located at the forward/port corner of the top-most cross-section of the polemast. The contours representing the (upper) von Mises stresses throughout the ECM compartment plating are presented in Figure 5.17(c), and show a maximum stress of 55.9 MPa in the starboard/aft corner of the ECM compartment plating at Level A. As shown by these contours, the stresses in all mast elements are well below yield for this loading case.

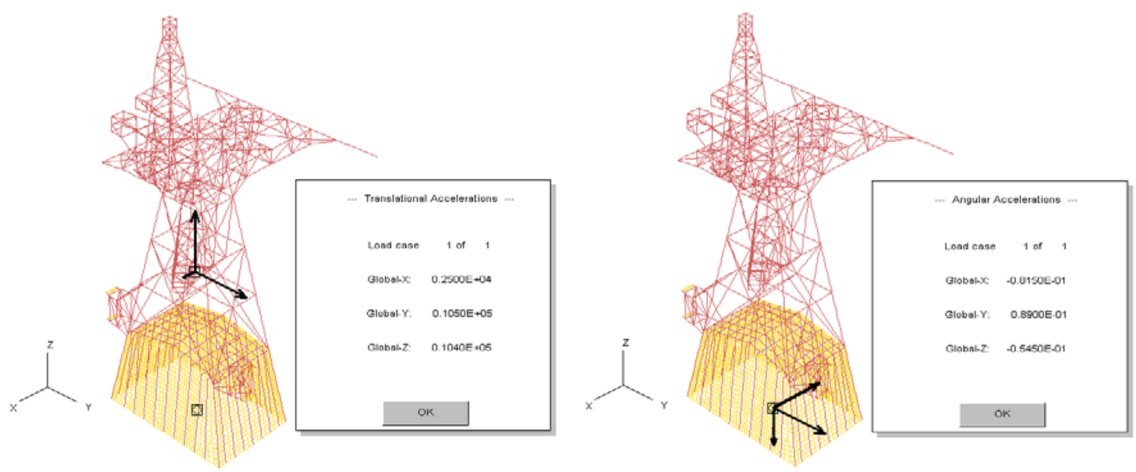
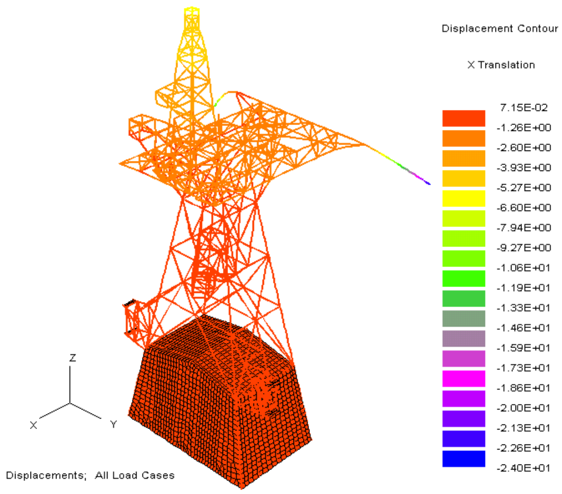
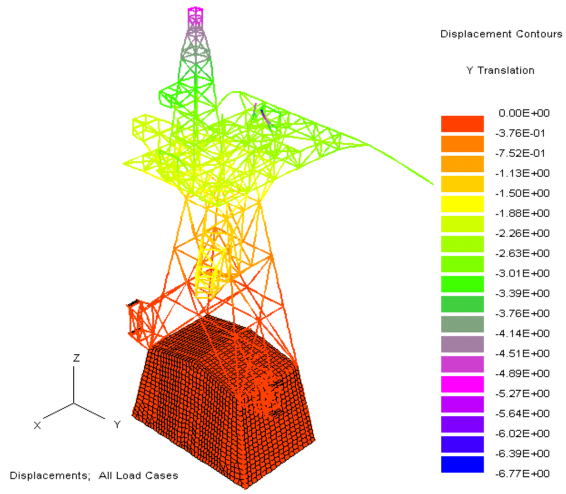


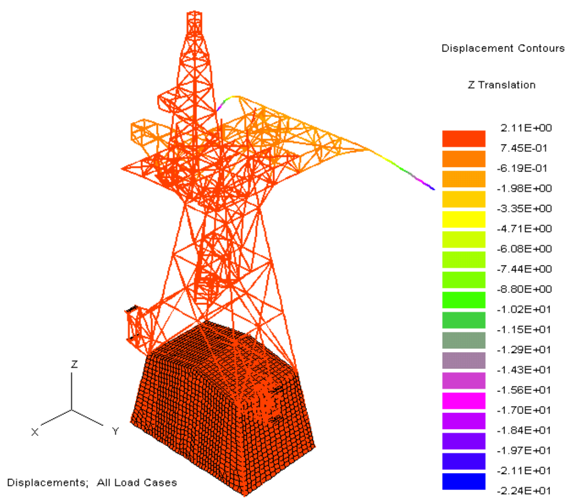

**Figure 5.15: Sea state 5 ship motions applied to the CPF Mast**




(a) Longitudinal

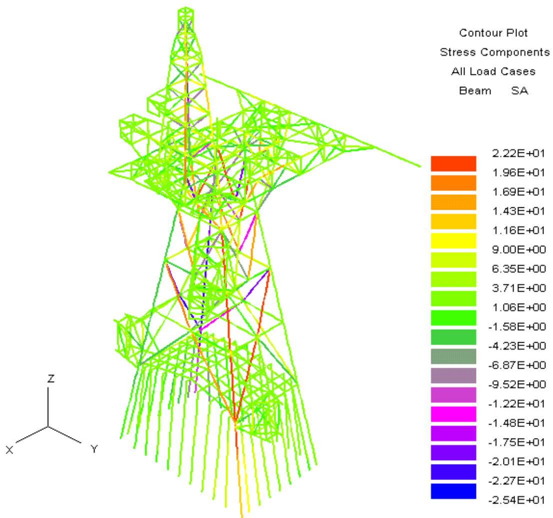



(b) Athwartship

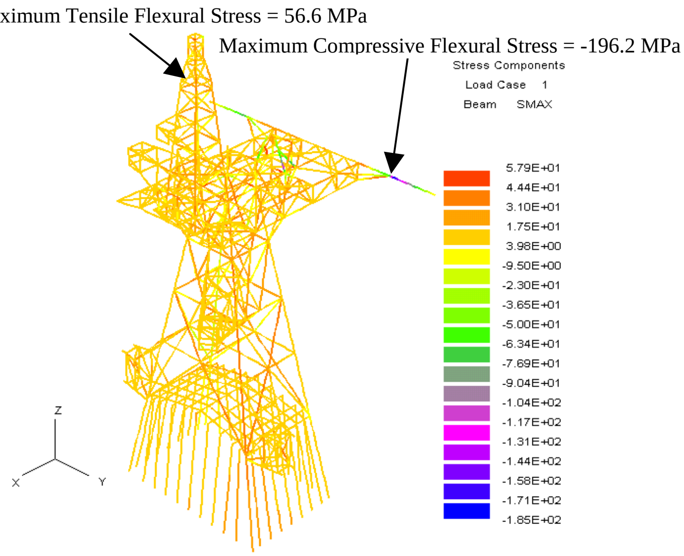



(c) Vertical

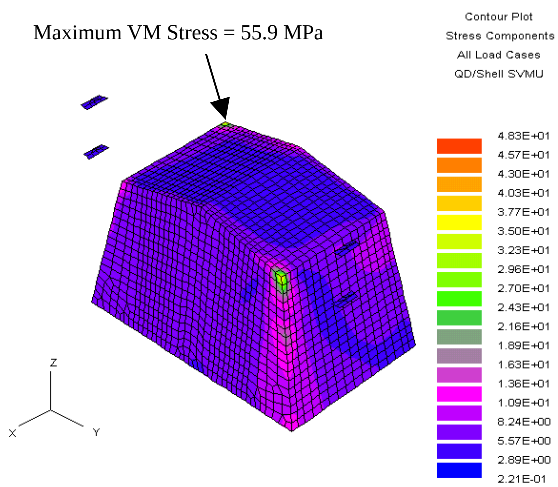
**Figure 5.16: CPF Mast displacement contours under SS5 ship motions**




(a) Axial stresses




(b) Maximum stresses




(c) von Mises stresses (upper) in ECM compartment plating

**Figure 5.17: Stress contours for SS5 ship motions applied to the CPF Mast**

# 6. MODELING AND ANALYSIS OF AN ENCLOSED STIFFENED STEEL MAST (EXAMPLE 5)

## 6.1 Problem Description

Information concerning the use and design of enclosed masts is rather scarce at present. The steel enclosed mast used by the Dutch Navy (referred to hereafter as the Dutch Mast) was therefore selected to demonstrate MASTSAS' capabilities in modelling enclosed mast configurations. The Dutch Mast is comprised of a number of polygonal cross-sections, whose dimensions vary along its height. The walls of the mast consist of a series of vertical stiffened panels. Mast equipment such as radar and other electronics are completely enclosed within the mast, and supported by horizontal stiffened plates at each major elevation along the mast's height. Each stiffened plate includes a circular cut-out at its center. Application of the MASTSAS software to the Dutch Mast is more thoroughly detailed in the following sections.

## 6.2 Model Development

The main section of the Dutch Mast consists of six-sided polygonal cross-sections, while the cross-sections comprising the top-most bay are rectangular and offset slightly from the mast centerline. Modelling this configuration presented a number of challenges to the MASTSAS system, including:

- creating irregular polygonal and rectangular cross sections through degeneration of hexagonal cross sections, and
- placing more than a single cross-section at a given elevation.

Details of the Dutch Mast configuration were obtained by means of a series of working drawings provided by Theo Bosman of the Royal Dutch Navy ("MAST OP B DEK SPT 97,5-101", Vol. 5480A). The overall height of the mast is approximately 9600mm, with major cross-sections identified at elevations of 2500mm, 4500mm, 6750mm, 8500mm, and 9600mm. All cross-sections were generated by manually entering the nodal coordinates of each six-sided cross-section. A typical numbering scheme for the faces and local co-ordinate points of each cross section is illustrated in Figure 6.1 below. The **C*rossSectionProperties*** page (see Figure 6.2) can be accessed for each cross-section to verify its local 2-D nodal coordinates and make any modifications if necessary. Cross-sectional dimensions at the major elevations throughout the Dutch Mast are summarized in Tables 6.1 and 6.2. It should be noted the mast deck at an elevation of 8500mm was modelled as two individual MASTSAS cross sections, namely an outer six-sided polygonal cross-section and an inner rectangular cross-section (which was created by degeneration of the assumed hexagonal cross section).

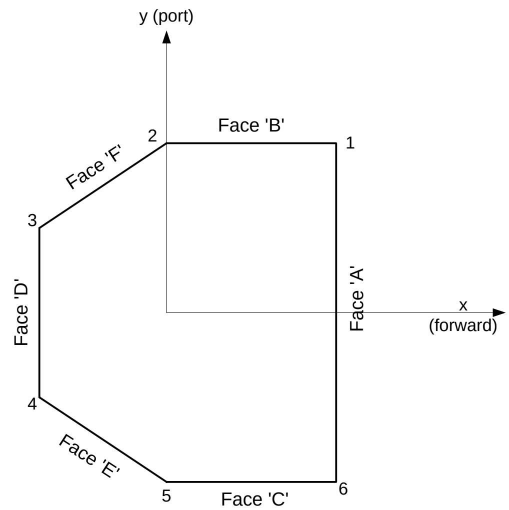



**Figure 6.1: Numbering scheme for a typical cross section of the Dutch Mast**

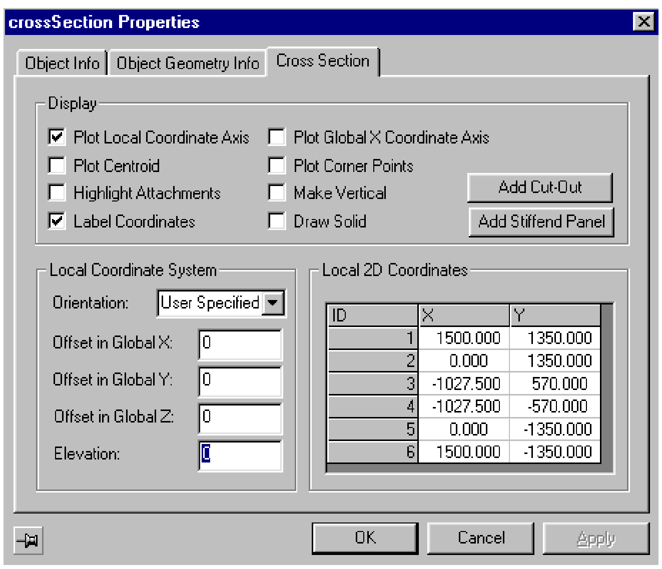



**Figure 6.2: Modifying cross-sectional coordinates**

**Table 6.1: Cross-section (CS) nodal coordinates for the Dutch Mast (CS01-CS04)**

| **Node ID** | **CS01: Level 0** Elevation: 0mm 6-Sided Polygon | | **CS02: Level 1** Elevation: 2500mm 6-Sided Polygon | | **CS03: Level 2** Elevation: 4500mm 6-Sided Polygon | | **CS04: Level 3** Elevation: 6750mm 6-Sided Polygon | |
|---|---|---|---|---|---|---|---|---|
| | **x (mm)** | **y (mm)** | **x (mm)** | **y (mm)** | **x (mm)** | **y (mm)** | **x (mm)** | **y (mm)** |
| 1 | 1500.0 | 1350.0 | 1324.4 | 1188.2 | 1184.0 | 1058.7 | 1026.0 | 913.0 |
| 2 | 0.0 | 1350.0 | 0.0 | 1188.2 | 0.0 | 1058.7 | 0.0 | 913.0 |
| 3 | -1027.5 | 570.0 | -968.8 | 570.0 | -921.8 | 570.0 | -869.0 | 570.0 |
| 4 | -1027.5 | -570.0 | -968.8 | -570.0 | -921.8 | -570.0 | -869.0 | -570.0 |
| 5 | 0.0 | -1350.0 | 0.0 | -1188.2 | 0.0 | -1058.7 | 0.0 | -913.0 |
| 6 | 1500.0 | -1350.0 | 1324.4 | -1188.2 | 1184.0 | -1058.7 | 1026.0 | -913.0 |

**Table 6.2: Cross-section (CS) nodal coordinates for the Dutch Mast (CS05-CS07)**

| Node ID | CS05: Level 4 Ext Elevation: 8500mm 6-Sided Polygon | | CS06: Level 4 Int Elevation: 8500mm Rectangular[a] | | CS07: Level 5 Elevation: 9600mm Rectangular[a] | |
|---|---|---|---|---|---|---|
| | x (mm) | y (mm) | x (mm) | y (mm) | x (mm) | y (mm) |
| 1 | 1189.0 | 800.0 | 1115.0 | 680.0 | 1060.0 | 680.0 |
| 2 | 0.0 | 800.0 | 0.0 | 680.0 | -55.0 | 680.0 |
| 3 | -800.0 | 570.0 | 0.0 | 113.3 | -55.0 | 113.3 |
| 4 | -800.0 | -570.0 | 0.0 | -113.3 | -55.0 | -113.3 |
| 5 | 0.0 | -800.0 | 0.0 | -680.0 | -55.0 | -680.0 |
| 6 | 1189.0 | -800.0 | 1115.0 | -680.0 | 1060.0 | -680.0 |
| [a] – Hexagonal CS degenerated to rectangular CS by moving points 3 and 4 | | | | | | |

The Dutch Mast was modelled using the following material properties: E=206,000 MPa, $\nu$=0.30, $\rho$=7.80x10$^{-9}$ Ns$^2$/mm$^4$, and $\sigma_{yld}$=355 MPa. Detailed information regarding stiffener scantlings and plating was obtained using a series of working drawings and other information provided by Mr. Bosman. Stiffeners designated as type 'T3', in combination with 4mm thick steel plating, were selected for all exterior stiffened panels throughout the height of the mast. The properties of the T3 stiffener sections are presented in Table 6.3.

**Table 6.3: Section properties for T3 stiffeners used in the Dutch Mast**

| Section Property | Value |
|---|---|
| Stiffener depth (d) | 74 mm |
| Flange breadth (b) | 25 mm |
| Web thickness (w) | 4.44 mm |
| Flange thickness (t) | 6.35 mm |
| Area (A) | 455 mm$^2$ |
| Neutral axis location ($y_{NA}$, wrt top) | 27.3 mm |
| Moments of Inertia ($I_{xx}$)<br>($I_{yy}$) | 0.259x10$^6$ mm$^4$<br>0.008x10$^6$ mm$^4$ |

Typical stiffener spacings were found to vary considerably from one bay/face to another throughout the mast, but were determined as closely as possible using information presented in the working drawings. Due to limited information concerning stiffeners in the exterior panels enclosing the uppermost bay of the mast, typical stiffener spacing patterns were assumed similar to those of the four lower bays. Three interior decks were then added to the mast at cross-sections CS02, CS03, and CS04. A single rectangular cut-out was then added to each interior deck panel using the *MastCutoutProperties* page shown in Figure 6.3. The cut-out properties are summarized in Table 6.4.

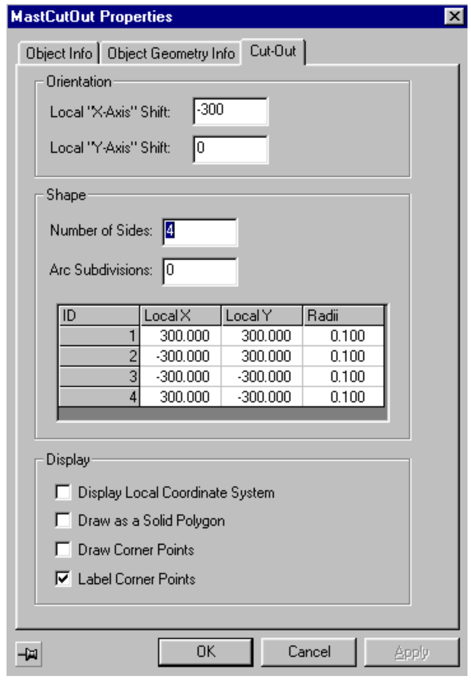



**Figure 6.3: Addition of cut-outs to cross-sections of the Dutch Mast**

**Table 6.4: Dutch Mast cross-sectional cut-out properties**

| Cross Section | Cut-out Size | Local Axis Offsets | |
|---|---|---|---|
| | | X-Shift | Y-Shift |
| CS02, Elevation = 2500mm | 600mm x 600 mm | -300.0mm | 0.0mm |
| CS03, Elevation = 4500mm | 600mm x 600 mm | +364.0mm | +600.0mm |
| CS04, Elevation = 6750mm | 600mm x 600 mm | -300.0mm | -50.0mm |

As the current version of MASTSAS cannot accommodate stiffened panels with more than four sides, the outer polygonal cross-section panel at CS05 (8500mm) was assumed to be unstiffened for the sake of analysis. The interior deck panels at CS02, CS03, and CS04 were likewise modelled as unstiffened, as was the degenerated hexagonal roof cross section. In an effort to compensate for this, the assumed plating thickness (4mm) for each of these panels was replaced by an ‘equivalent’ thickness, computed such that the masses of the individual unstiffened panels would be comparable to those of the stiffened panel configurations depicted in the working drawings. The resulting equivalent thickness for each deck panel are as follows:

- 5.5mm at CS02 (elevation 2500mm)
- 5.8mm at CS03 (elevation 4500mm)
- 6.0mm at CS04 (elevation 6750mm)
- 5.9mm at CS05 (elevation 8500mm)
- 6.0mm at CS07 (roof) (elevation 9600mm)

Boundary conditions were then applied to the Dutch mast, assuming the base to be completely restrained against both translation and rotation. A finite element mesh was generated using MASTSAS’ automatic meshing feature, with a default element size of

approximately 100mm.  The resulting geometry and finite element mesh are shown in Figure 6.4.  The finite element model was then exported to a DSA database, which was then used in conjunction with the VAST solver to perform both an eigenvalue analysis and a wind loading analysis on the Dutch Mast.

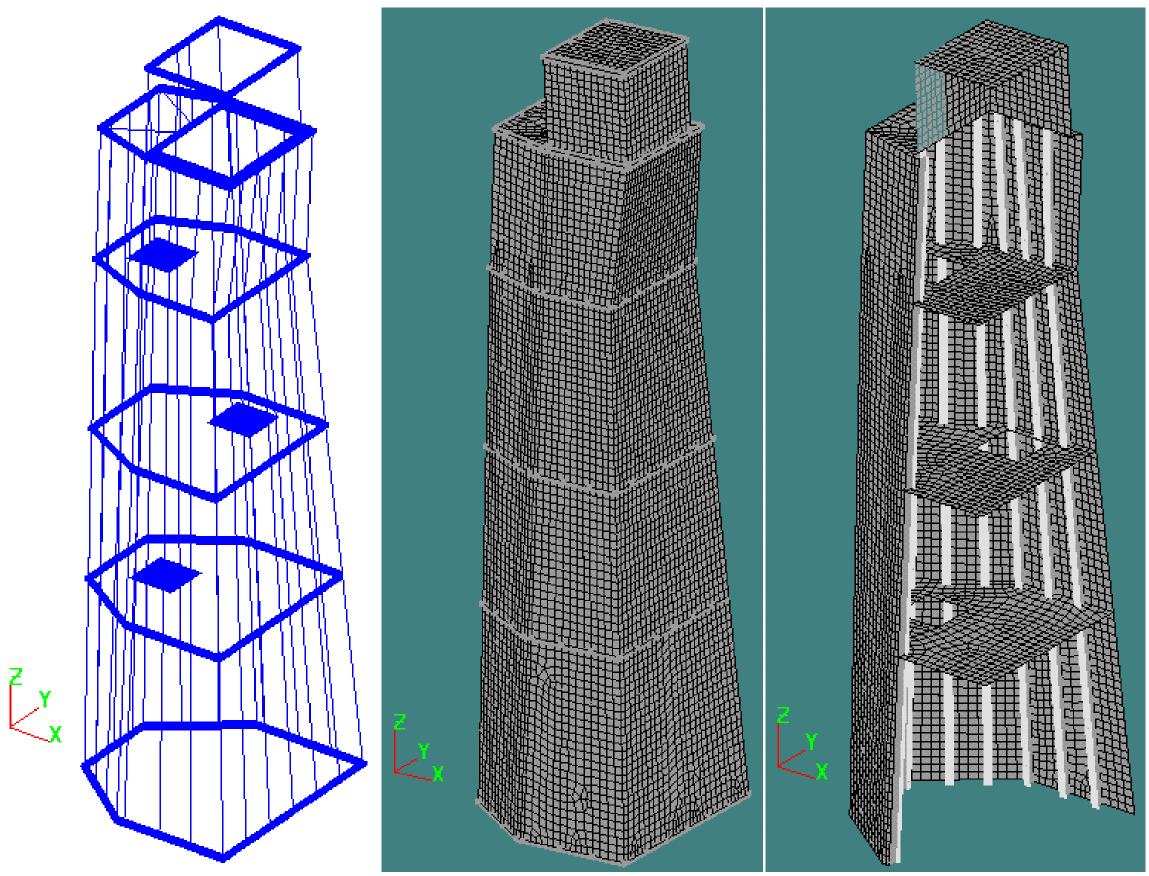



**Figure 6.4: Geometric and finite element models of the Dutch Mast**

## 6.3 Analysis

### 6.3.1 Eigenvalue Analysis

The first analysis performed on the Dutch Mast model was a natural frequency analysis. The analysis was carried out using a consistent mass matrix formulation and direct iteration, along with DSA's sparse solver.  The mass of the entire mast was computed as 3515 kg.  The first ten natural frequencies are summarized in Table 6.5.  The first three modes of vibration are dominated by local vibration of the deck panels at CS02, CS03, and CS04, respectively, while modes 4 and 5 depict additional vibration modes at CS02. The sixth mode (23.06 Hz) appears to be the first significant longitudinal mode, while the eighth mode (24.35 Hz) represents the first significant athwartship mode.  Similarly, the highest modal participation factors for longitudinal and athwartship vibrations were found for modes 6 and 8, respectively.  It should be noted that these frequencies do not include the effect of any mast equipment, for which mass and location information was

unavailable. As a result, it is highly likely that the actual frequencies for the mast are significantly less than those reported here.

**Table 6.5: Natural frequencies (Hz) for the Dutch Mast**

| Mode No. | Natural Frequency (Hz) |
|---|---|
| 1 | 9.39 |
| 2 | 11.59 |
| 3 | 15.88 |
| 4 | 18.14 |
| 5 | 21.39 |
| **6** | [1,3] **23.06** |
| 7 | 23.57 |
| **8** | [2,4] **24.35** |
| 9 | 25.59 |
| 10 | 28.88 |

1 – First significant longitudinal vibration mode
2 – First significant athwartship vibration mode
3 – Highest modal participation factor (longitudinal)
4 – Highest modal participation factor (athwartship)

### 6.3.2 Wind Loading Analysis

A 120-knot wind out of the aft direction, a commonly specified load case for analysis of mast structures, will constitute the applied loading in this analysis. The wind loads were computed assuming an air density of $1.205 \times 10^{-12}$ $Ns^2/mm^4$. The applied wind loading is shown in Figure 6.5.

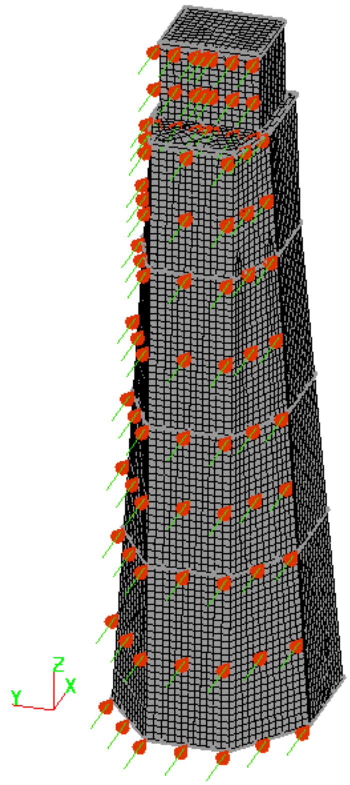



**Figure 6.5: 120-knot aft wind applied to the Dutch Mast**

The resulting displacement contours are presented in Figure 6.6. A resultant displacement of approximately 0.97mm was computed over the entire roof surface at CS07 (elevation 9600mm), with a maximum displacement of 1mm computed at node 2638, located near the center of the aft-facing stiffened panel spanning the top-most bay of the mast. A resultant displacement of approximately 0.65mm was observed along both the forward and aft edges of the mast at CS05 (elevation 8500mm).

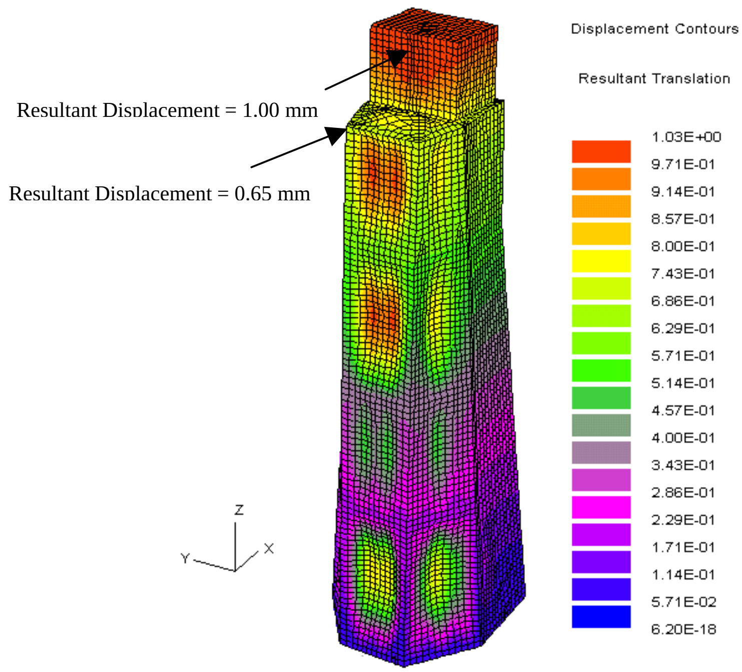
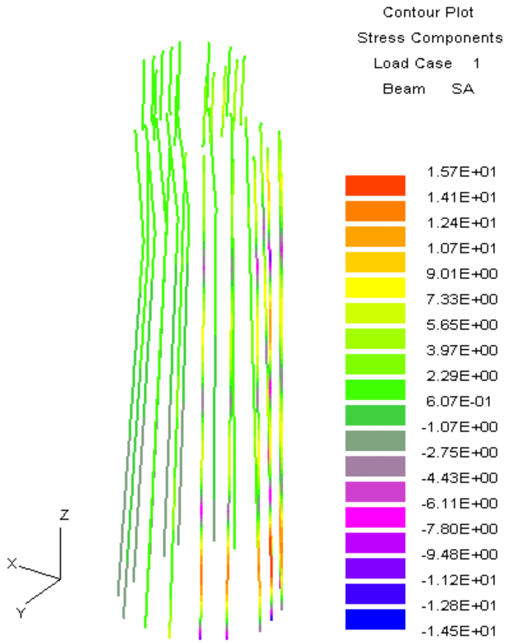
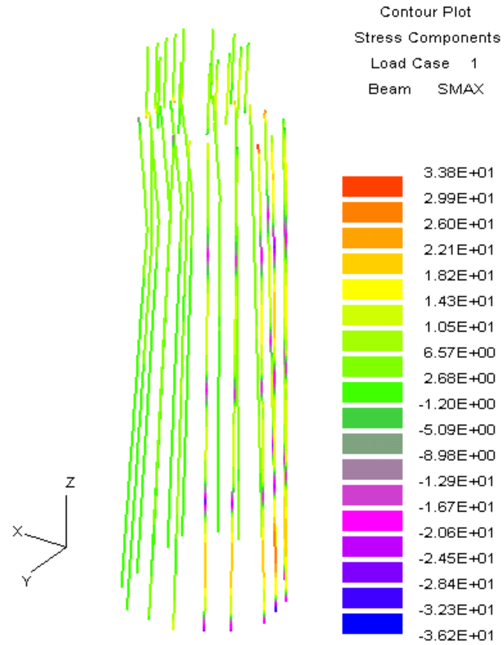



**Figure 6.6: Displacement contours for 120-knot aft wind applied to the Dutch Mast**

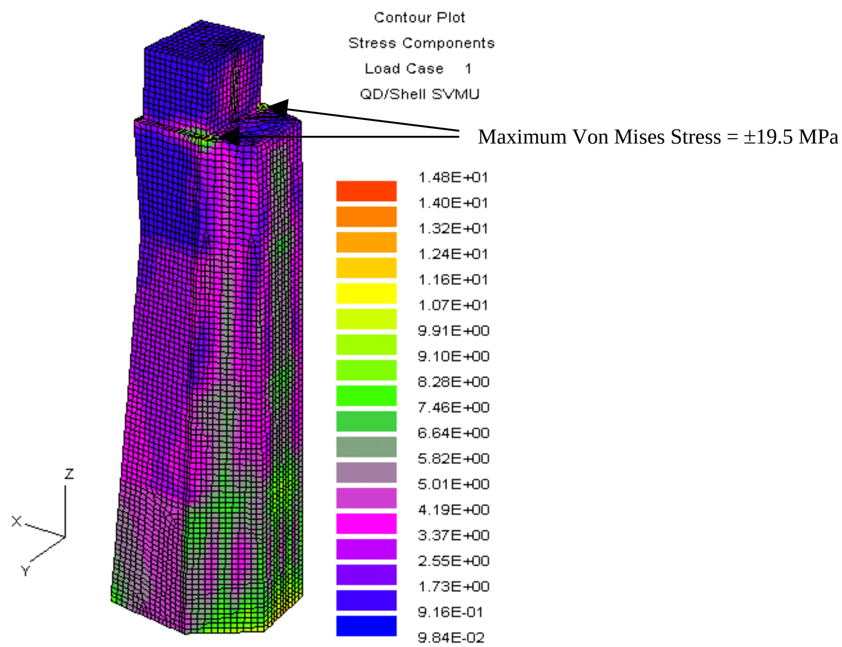
Wind-induced element stress contours are presented in Figure 6.7. The axial stresses in the panel stiffeners, presented in Figure 6.7(a), suggest rather modest axial stresses in the mast panel stiffeners, with a maximum axial stress of 15.82 MPa computed for element 9937, located in the center-most stiffener of the aft-facing panel in the lower bay. The corresponding maximum stress plot of Figure 6.7(b) indicates maximum compressive flexural stresses of –36.18 MPa for element 9924, located in the center-most aft-facing panel stiffener at the base of the mast. A maximum tensile flexural stress of 33.77 MPa is reported in element 11135, located in an aft-facing panel stiffener at CS05 (elevation 8500mm). The (upper) von Mises stresses presented in Figure 6.7(c) suggest maximum stresses of approximately 19.5 MPa in the plating of the port and starboard corners of the aft-facing panel of the top-most bay of the mast. In all cases, the contours clearly show that all components of the mast are well below yield when subjected to the 120 knot aft wind.




(a) Axial stresses




(b) Maximum stresses




(c) Von Mises stresses (upper) in mast panel plating

**Figure 6.7: Stress contours from 120-knot aft wind applied to the Dutch Mast**

The small stresses and displacements computed for this load case are due in part to the various assumptions made in lieu of more detailed geometric information. It should again be noted that information concerning the mass distribution of mast equipment was unavailable for the analysis. Nevertheless, the example does effectively demonstrate MASTSAS' capabilities in modeling/analysis of the Dutch Mast.

# 7. MODELING AND ANALYSIS OF An ENCLOSED COMPOSITE MAST (EXAMPLE 6)

## 7.1 Problem Description

The Advanced Enclosed Mast/Sensor (AEM/S) System is the US Navy's newest mast, installed aboard the *Spruance-Class* destroyer, USS *Arthur Radford*, in May 1997. The AEM/S System, hereafter referred to as the US Mast, is a multi-level enclosed mast, made of advanced hybrid composite materials. Radar and other equipment are enclosed within the mast, thereby protecting them from the environment. The US Mast was selected to demonstrate MASTSAS' capabilities in modelling both enclosed mast configurations and composite materials.

## 7.2 Model Development

The lower portion of the main trunk of the US Mast is of hexagonal configuration, while the upper portion is comprised of both hexagonal and rectangular cross sections, offset from the mast centerline in the forward direction. Modelling this configuration presented a number of challenges, including:

- placing more than one cross-section at the same elevation
- properly assigning offsets for cross sections in the upper portion of the main trunk, and
- creation of rectangular cross sections through degeneration of hexagonal cross sections.
- inserting laminate materials

Details of the mast configuration were obtained from Benson et al. (1998). Cross-sectional dimensions for the various elevations comprising the main trunk of the structure are summarized in Table 7.1. Four interior decks were then added to the mast at cross-sections CS02, CS03, CS05 and CS07. Due to limited information, the deck panels were modelled as unstiffened sections. The *MastCutoutProperties* page shown in Figure 7.1 was then used to add a single cut-out to each interior deck panel. The deck panel cut-out properties are summarized in Table 7.2. A graphite-reinforced plastic (GRP) laminate GY-70/934 was selected for all panels of the enclosed mast. Properties of the GY-70/934 lamina are presented in Table 7.3. The symmetric GRP laminate is comprised of a total of eleven 0.05in thick layers in an alternating 0°-90° layup sequence. As shown in Figure 7.2, the laminate was created and inserted into the MASTSAS material database through the main menu by selecting *Properties* → *Materials* → *Insert* → *OrthotropicLaminaMaterial*. Lamina materials, orientations, and thickness are then specified using the *Laminate Properties* page shown in Figure 7.3. Individual layers are added one at a time and their properties specified. In this example, the GY-70/934 material is selected for all lamina by using the '*Cascade*' feature.

Table 7.1: Summary of cross-sectional (CS) dimensions for the US Mast

| CS No. | Identification | Cross Section Shape | Elevation (in) | Side Length (in) | Centerline Offset (in) |
|---|---|---|---|---|---|
| 01 | Base Elevation (HVAC level) | Hexagonal | 0 | 117.1 | 0.0 |
| 02 | SPS40 Antenna Base | Hexagonal | 350 | 186.0 | 0.0 |
| 03 | TAS Antenna Base | Hexagonal | 596 | 139.6 | 0.0 |
| 04 | Top of Main Trunk | Hexagonal | 788 | 103.3 | 0.0 |
| 05 | ROS Base | Hexagonal | 788 | 73.0 | 25.0 |
| 06 | ROS Top | Hexagonal | 872 | 66.5 | 25.0 |
| 07 | Base of Integrated Comm. Antenna | Rectangular [a] | 872 | 42.5 | 52.0 |
| 08 | Top of Integrated Comm. Antenna | Rectangular [a] | 1053 | 42.5 | 33.2 |

[a] – Hexagonal CS degenerated to rectangular by moving cross section points 3 and 6

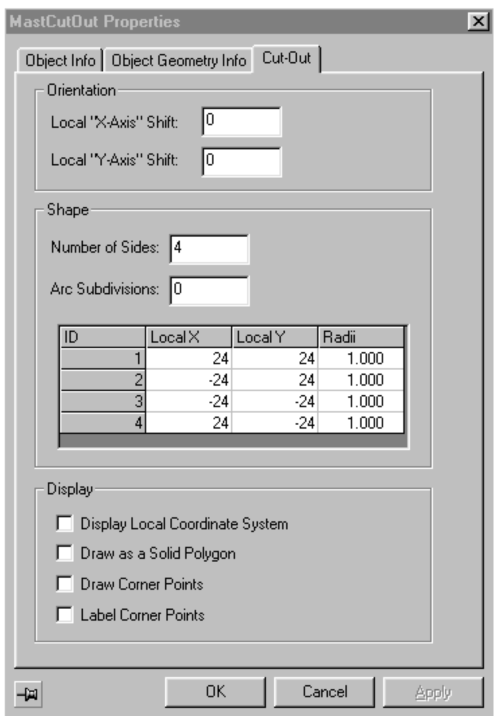



Figure 7.1: Addition of cut-outs to cross-sections of the US Mast

Table 7.2: Cross-sectional cut-out properties for the US Mast

| Cross Section | Cut-out Size* |
|---|---|

| | |
|---|---|
| CS02, Elevation = 350in | 48in x 48in |
| CS03, Elevation = 596in | 48in x 48in |
| CS05, Elevation = 788in | 36in x 36in |
| CS07, Elevation = 872in | 24in Diameter |
| * - All cut-out offsets are zero with respect to the local origin of the cross section to which they apply | |

**Table 7.3: Material properties of graphite-reinforced plastic GY-70/934**

| Property | Value |
|---|---|
| Assumed Fiber Volume Fraction, $V_f$ (-) | 0.570 |
| Density, $\rho$ ($lbs^2/in^4$) | $1.487 \times 10^{-4}$ |
| Longitudinal Modulus, $E_{11}$ (psi) | $42.630 \times 10^{6}$ |
| Transverse Moduli, $E_{22} \cong E_{33}$ (psi) | $0.920 \times 10^{6}$ |
| Shear Moduli, $G_{12} \cong G_{23} \cong G_{13}$ (psi) | $0.710 \times 10^{6}$ |
| Major Poisson Ratios, $\nu_{12} \cong \nu_{23} \cong \nu_{13}$ | 0.230 |
| Longitudinal Tensile Strength, $F_{1t}$ (psi) | $85.300 \times 10^{3}$ |
| Transverse Tensile Strengths, $F_{2t} \cong F_{3t}$ (psi) | $4.300 \times 10^{3}$ |
| Longitudinal Compressive Strength, $F_{1c}$ (psi) | $71.100 \times 10^{3}$ |
| Transverse Compressive Strengths, $F_{2c} \cong F_{3c}$ (psi) | $14.200 \times 10^{3}$ |
| Shear Strengths, $F_{12} \cong F_{23} \cong F_{13}$ (psi) | $7.110 \times 10^{3}$ |
| Longitudinal Thermal Expansion Coefficient, $\alpha_1$ (/°F) | $-0.060 \times 10^{-6}$ |
| Transverse Thermal Expansion Coefficient, $\alpha_2$ (/°F) | $14.400 \times 10^{-6}$ |
| Longitudinal Moisture Expansion Coefficient, $\beta_1$ (-) | 0.000 |
| Transverse Moisture Expansion Coefficient, $\beta_2$ (-) | 0.300 |


**Figure 7.2: Inserting an *OrthotropicLaminaMaterial* into the MASTSAS Database**

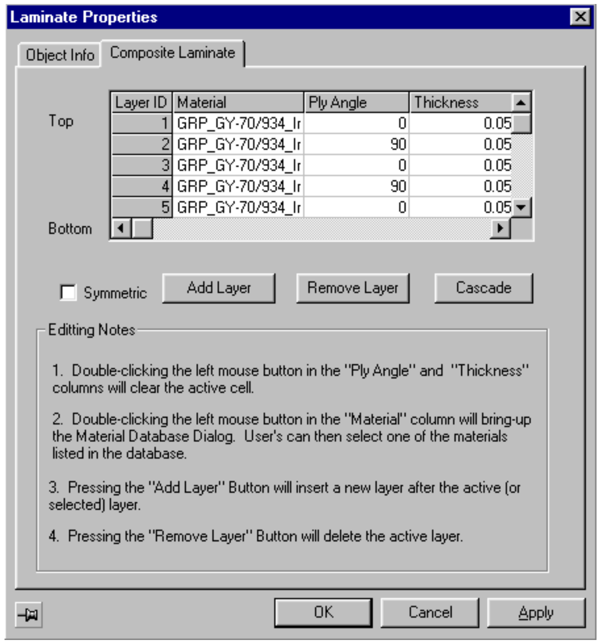



**Figure 7.3: Specification of laminate properties for the US Mast**

The final geometric and cross-sectional configuration of the US Mast structure is illustrated in the figures below.

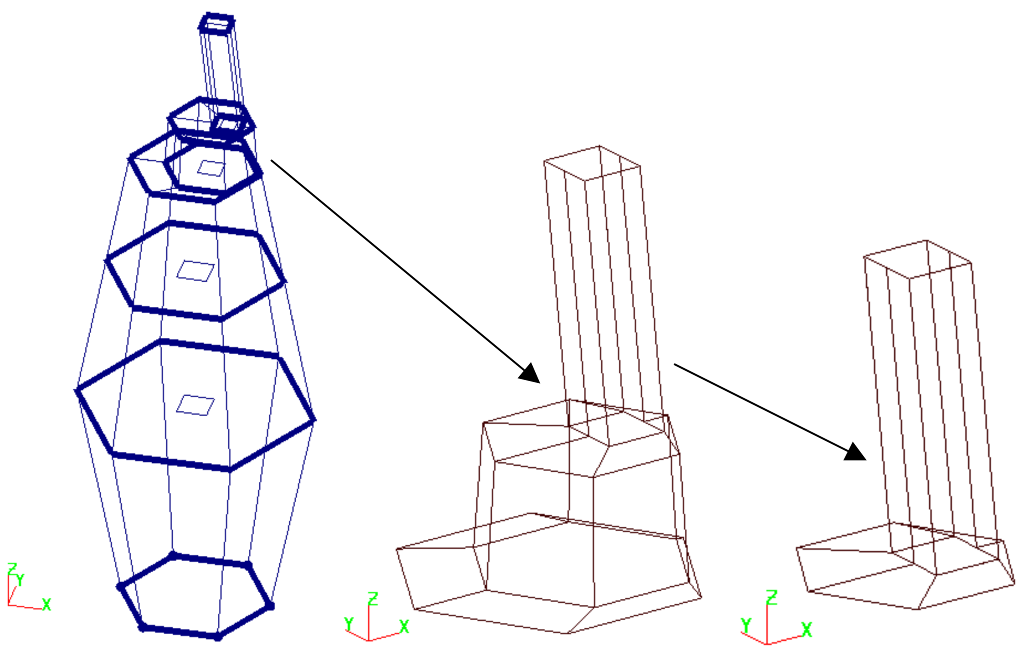


**Figure 7.4: Cross-sectional configuration of the (AEM/S System) US Mast**

Assuming its base to be completely fixed, boundary conditions were applied to the US Mast. A finite element mesh was generated using MASTSAS' automatic meshing feature, with a default element size of approximately 14in. The resulting finite element mesh, showing the interior deck panels and cut-outs, is shown in Figure 7.5 below. The

finite element model was then exported to a DSA database, which was then used in conjunction with the VAST solver to perform determine the mast's natural frequencies.

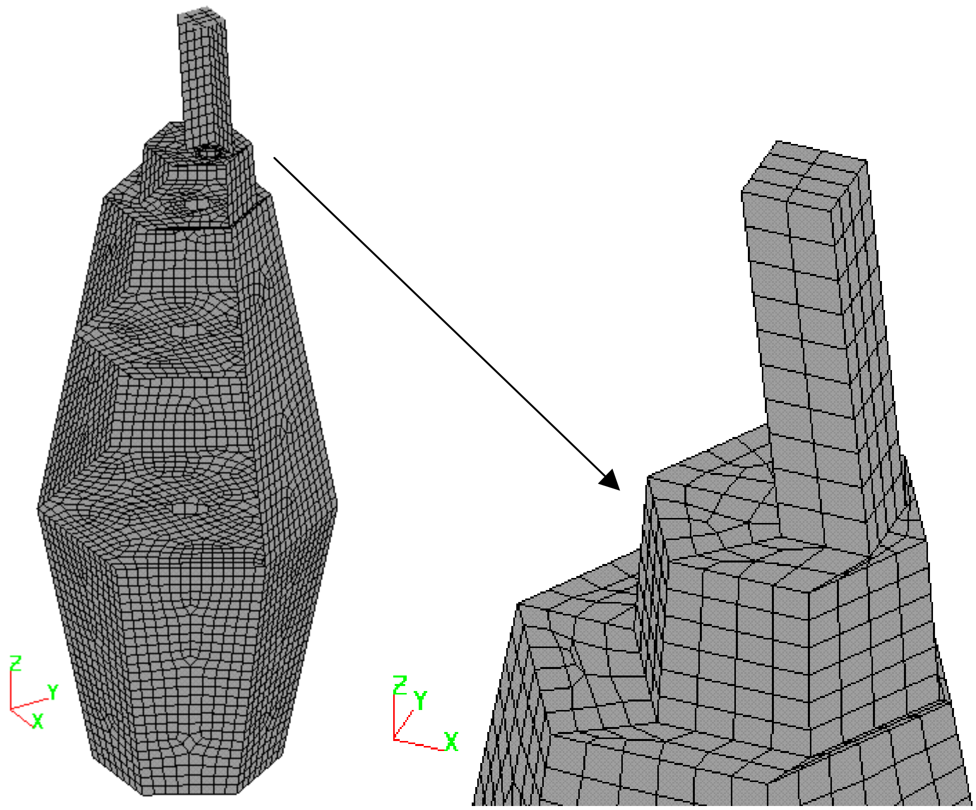



**Figure 7.5: Finite element model of the (AEM/S System) US Mast**

## 7.3 Eigenvalue Analysis

The eigenvalue analysis of the US Mast was carried out using a consistent mass matrix formulation and direct iteration, along with DSA's sparse solver. The mass of the entire mast was computed as 30,012lbs (~13,642kg). The first ten natural frequencies are summarized in Table 7.4. The vibrational modes considered depict a combination of longitudinal/lateral vibration of the integrated communications antenna (spanning the top-most bay), localized vibration of the interior deck panels, and dimpled deformation patterns on the exterior panels. Both the fundamental and second modes (~2.79Hz) of vibration are dominated by local deformation of the interior deck panels at CS02 and CS03, combined with longitudinal deformation and yawing of the integrated communications antenna. The first significant athwartship mode, which did not occur until mode 7 (5.73Hz), was dominated by athwartship motion of the integrated communications antenna, combined with a dimpled deformation pattern for the panels enclosing the lower bays. The resulting mode shapes for modes 1 and 7 are illustrated in Figure 7.6. The highest modal participation factors for longitudinal and yawing vibrations were both found for the fundamental mode, while the highest for athwartship vibrations occurred for mode 10.

**Table 7.4: US Mast natural frequencies (Hz)**

| Mode No. | Natural Frequency (Hz) |
|---|---|
| 1 | [1,3] **2.788** |
| 2 | 2.791 |
| 3 | 4.721 |
| 4 | 5.037 |
| 5 | 5.045 |
| 6 | 5.267 |
| 7 | [2] **5.728** |
| 8 | 5.764 |
| 9 | 6.059 |
| 10 | [4] **6.078** |

1 – First significant longitudinal/yawing vibration mode
2 – First significant athwartship vibration mode
3 – Highest modal participation factors (longitudinal/yawing)
4 – Highest modal participation factor (athwartship)

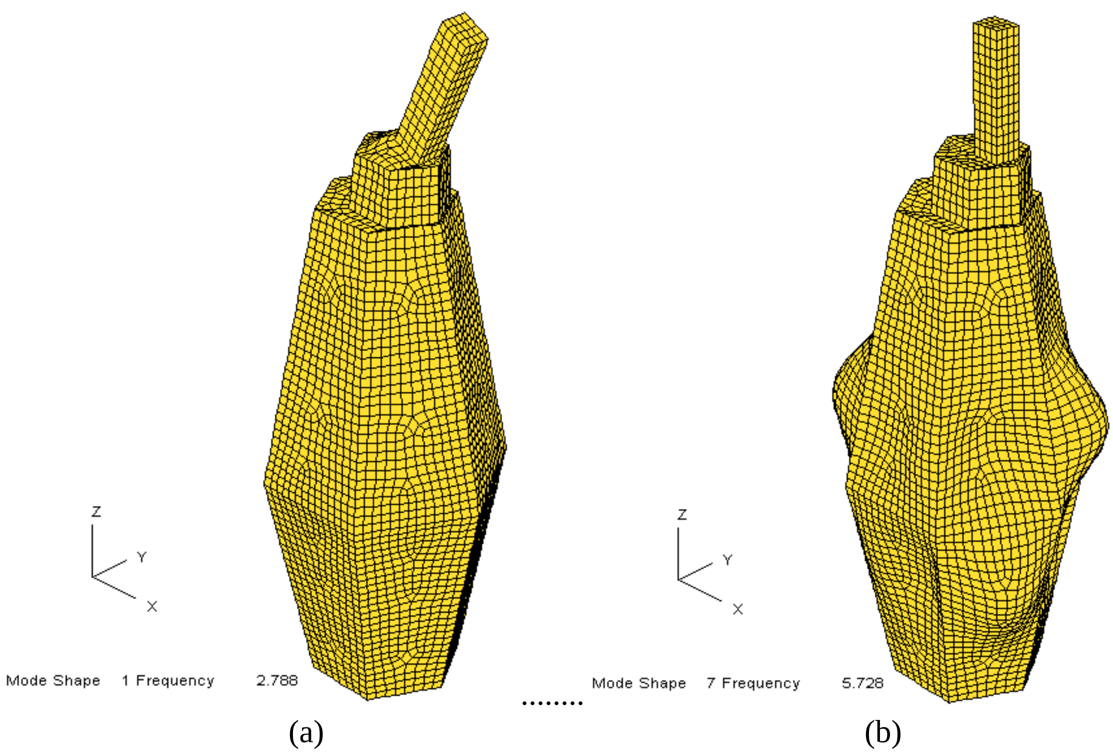



**Figure 7.6: Vibrational mode shapes for the US Mast (a) mode 1, and (b) mode 7**

# 8. REFERENCES

1. Norwood, M.E., "Validation of Lattice Mast Design Procedure: Comparison of Predicted and Measured Responses of a Model Mast Tested at Event Dicethrow" Final Report delivered to Department of National Defence, Contract 2SRS76-00083, March 1977.

2. Department of National Defence, Unclassified Working Drawings for Canadian Patrol Frigate, CPF Drawing # 8455596 Sheets 1-7.

3. Benson, J.L., Eadie, J., and Underwood, L. "The AEM/S System: From Research to Reality," Association of Scientists and Engineers, 35th Annual Symposium, 1998.

4. Smith, M.J. (2003), Private Communication.

5. Crocker, J., Delbridge, G., and Kumar, R., "Development of HyperVAST Model for IRO Mast – Phase I," Final Report delivered to Department of National Defence, September 1998.

6. MSEI (1994), "TRUMP MAIN MAST STRUCTURAL ANALYSIS, PHASE II ENGINEERING ASSESSMENT," Vol. I, Main Report, MIL Systems Engineering, August 1994, MSEI Report #394280-02.

7. YARD Inc. (1988), "CPF Main Mast Finite Element Analysis," Report No. 1052/88, YARD Inc., Ottawa, Ontario.

# 9. Appendix A: Geometry and Configuration of the Event Dicethrow Mast

| -NO | ITEM NO DE L'ART | IDENTIFYING NO D'IDENTIFICATION | NOMENCLATURE | DESCRIPTION | SPECIFICATION | NSCM CAOF |
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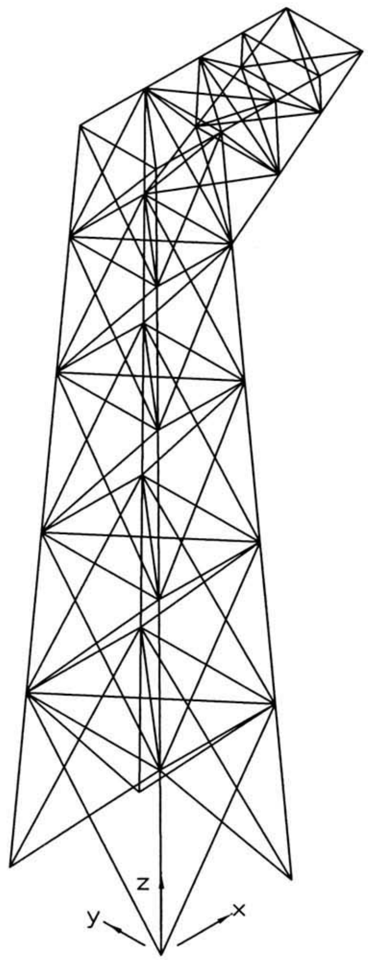
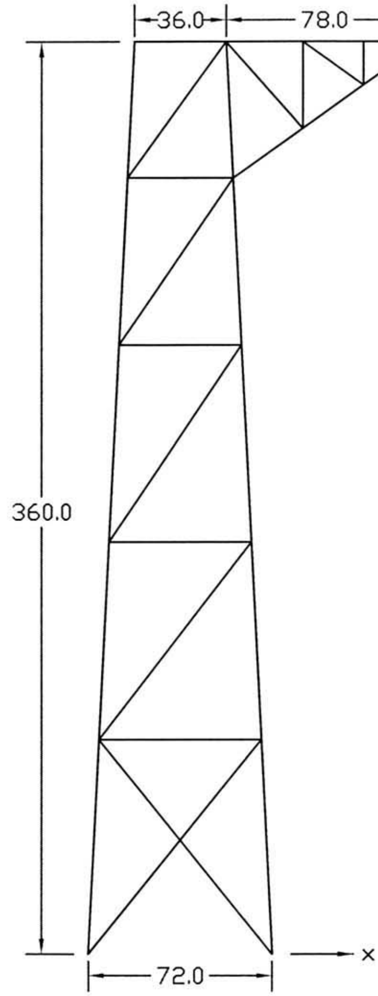
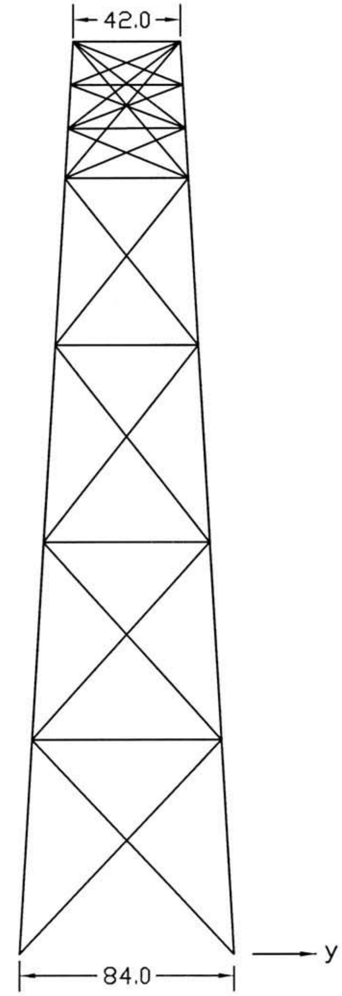



ISOMETRIC VIEW




FRONT VIEW




SIDE VIEW

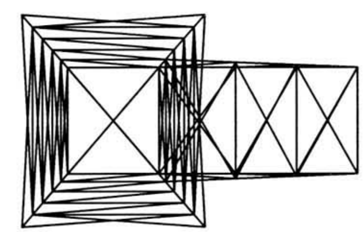
MATERIAL PROPERTIES

$E = 29.6 \times 10^{6}$

$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43,500$ psi



TOP VIEW

| | | |
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| CHECKED BY: VERIFIE: DR.T.S.KOKO | | MATERIAL: MATERIAU: XS STEEL |
| TOLERANCES: / DRAWN BY: DESSINE PAR: T.E.DUNBAR | DESCRIPTION: MAST – ISOMETRIC, FRONT, SIDE AND TOP VIEWS | PROJECT: PROJECT: 61013 |
| SCALE: ECHELLE: 1:75 | | |
| UNLESS OTHERWISE NOTED UNITS: UNITES: INCHES / DATE: 07 FEB 2003 | DRAWING NUMBER: NUMERO DE DESSIN: | SHEET FEUILLE 1 OF DE 7 |

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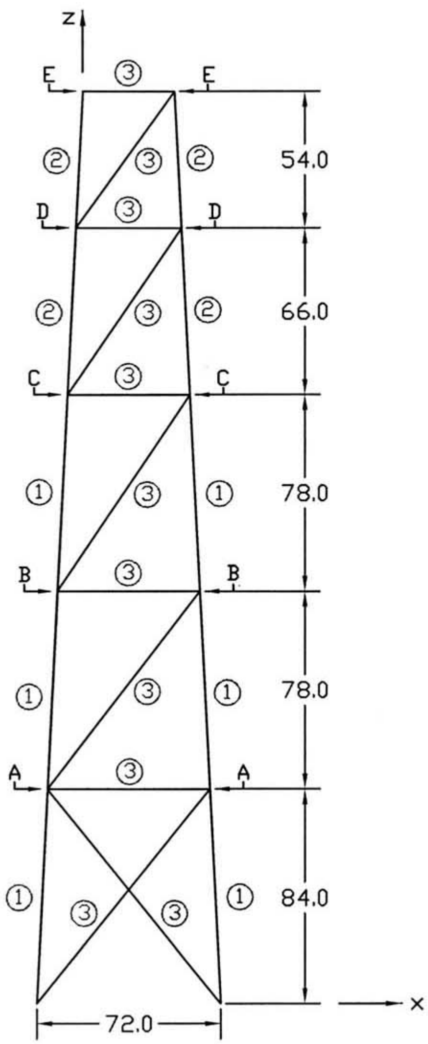
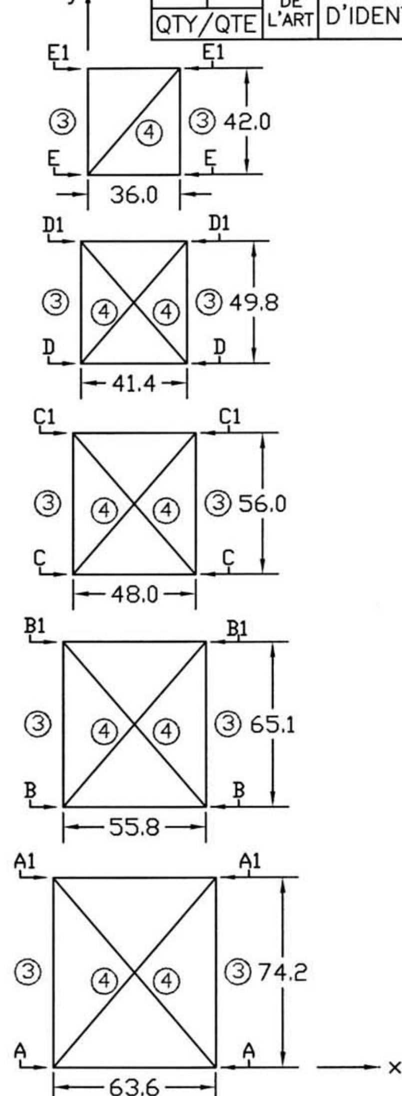
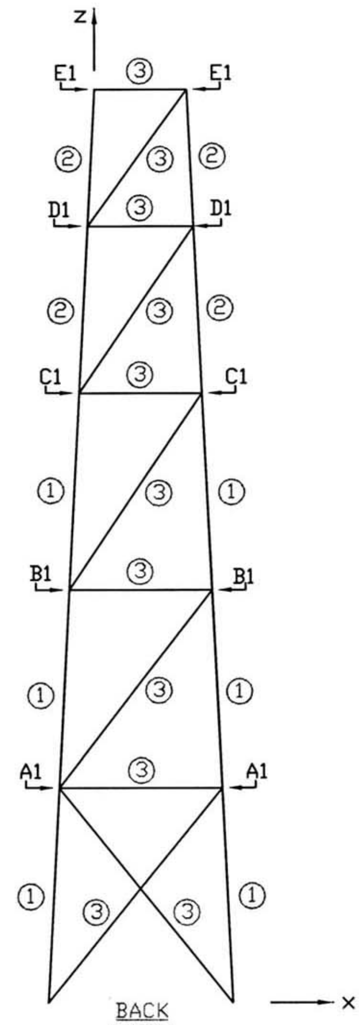



FRONT VIEW




TOP VIEWS




BACK VIEW

MATERIAL PROPERTIES

$E = 29.6 \times 10^6$

$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43{,}500$ psi

MEMBER DIAMETER (OD) AND THICKNESSES (T)

① - 4" (OD)
- 0.318" (T)

② - 3 1/2" (OD)
- 0.300" (T)

③ - 2 7/8" (OD)
- 0.276" (T)

④ - 2 3/8" (OD)
- 0.218" (T)

| | | | |
|---|---|---|---|
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| | CHECKED BY: VERIFIE: DR.T.S.KOKO | | MATERIAL: MATERIAU: XS STEEL |
| | DRAWN BY: DESSINE PAR: T.E.DUNBAR | DESCRIPTION: MAST – FRONT, BACK AND TOP VIEWS | PROJECT: PROJECT: 61013 |
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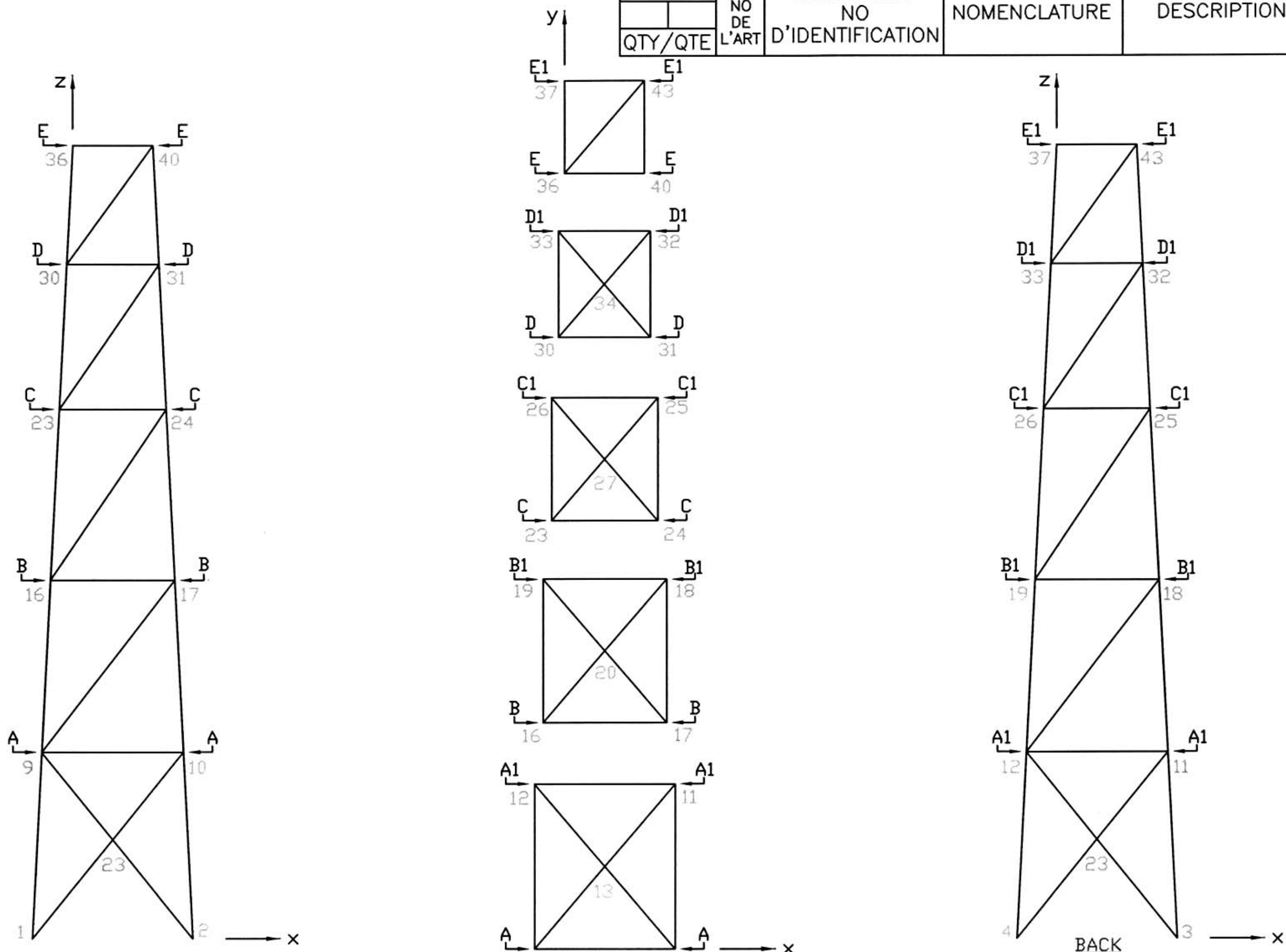


FRONT VIEW

TOP VIEWS

BACK VIEW

MATERIAL PROPERTIES

$E = 29.6 \times 10^6$

$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43{,}500$ psi

| | | | |
|---|---|---|---|
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| | CHECKED BY: VERIFIE: DR.T.S.KOKO | | MATERIAL: MATERIAU: XS STEEL |
| | DRAWN BY: DESSINE PAR: T.E.DUNBAR | | PROJECT: PROJECT: 61013 |
| | SCALE: ECHELLE: 1:75 | DESCRIPTION: MAST – FRONT, BACK AND TOP VIEWS | |
| UNLESS OTHERWISE NOTED UNITS: UNITES: INCHES | DATE: 07 FEB 2003 | DRAWING NUMBER: NUMERO DE DESSIN: | SHEET FEUILLE 3 OF DE 7 |

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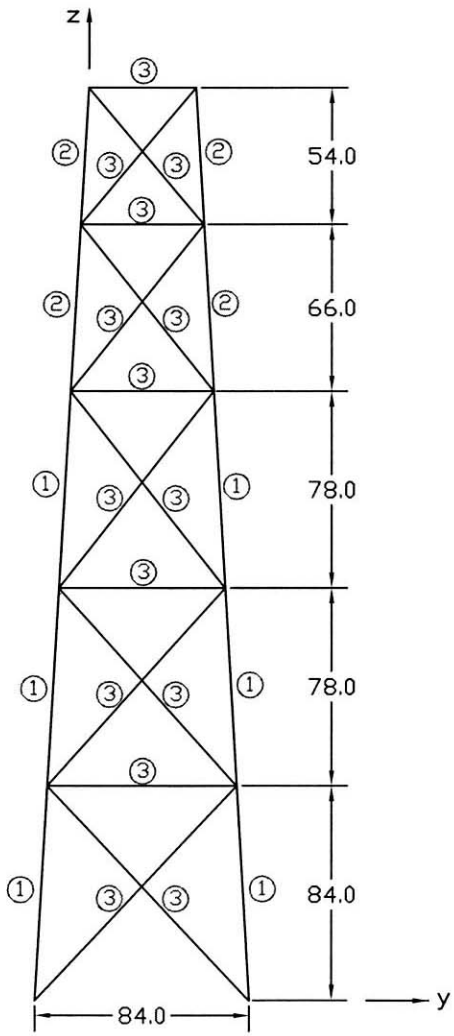
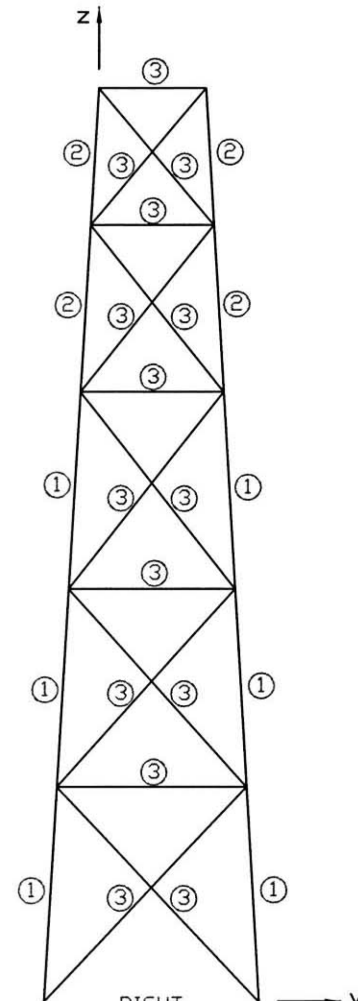



LEFT VIEW




RIGHT VIEW

MATERIAL PROPERTIES

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$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43{,}500$ psi

MEMBER DIAMETER (OD) AND THICKNESSES (T)

1 - 4" (OD)
- 0.318" (T)

2 - 3 1/2" (OD)
- 0.300" (T)

3 - 2 7/8" (OD)
- 0.276" (T)

4 - 2 3/8" (OD)
- 0.218" (T)

| | |
|---|---|
| TOLERANCES: | |
| UNLESS OTHERWISE NOTED UNITS: UNITES: INCHES | |
| APPROVED: APPROVE: | |
| CHECKED BY: VERIFIE: DR.T.S.KOKO | |
| DRAWN BY: DESSINE PAR: T.E.DUNBAR | |
| SCALE: ECHELLE: 1:75 | |
| DATE: 07 FEB 2003 | |

MARTEC LTD
1888 BRUNSWICK STREET, SUITE 400
HALIFAX, NS, B3J 3J8, CANADA

DESCRIPTION: MAST – SIDE VIEWS

DRAWING NUMBER: NUMERO DE DESSIN:

SIZE: GRANDEUR: | QUANTITY: QUANTITE:

MATERIAL: MATERIAU: XS STEEL

PROJECT: PROJECT: 61013

SHEET FEUILLE 4 OF DE 7

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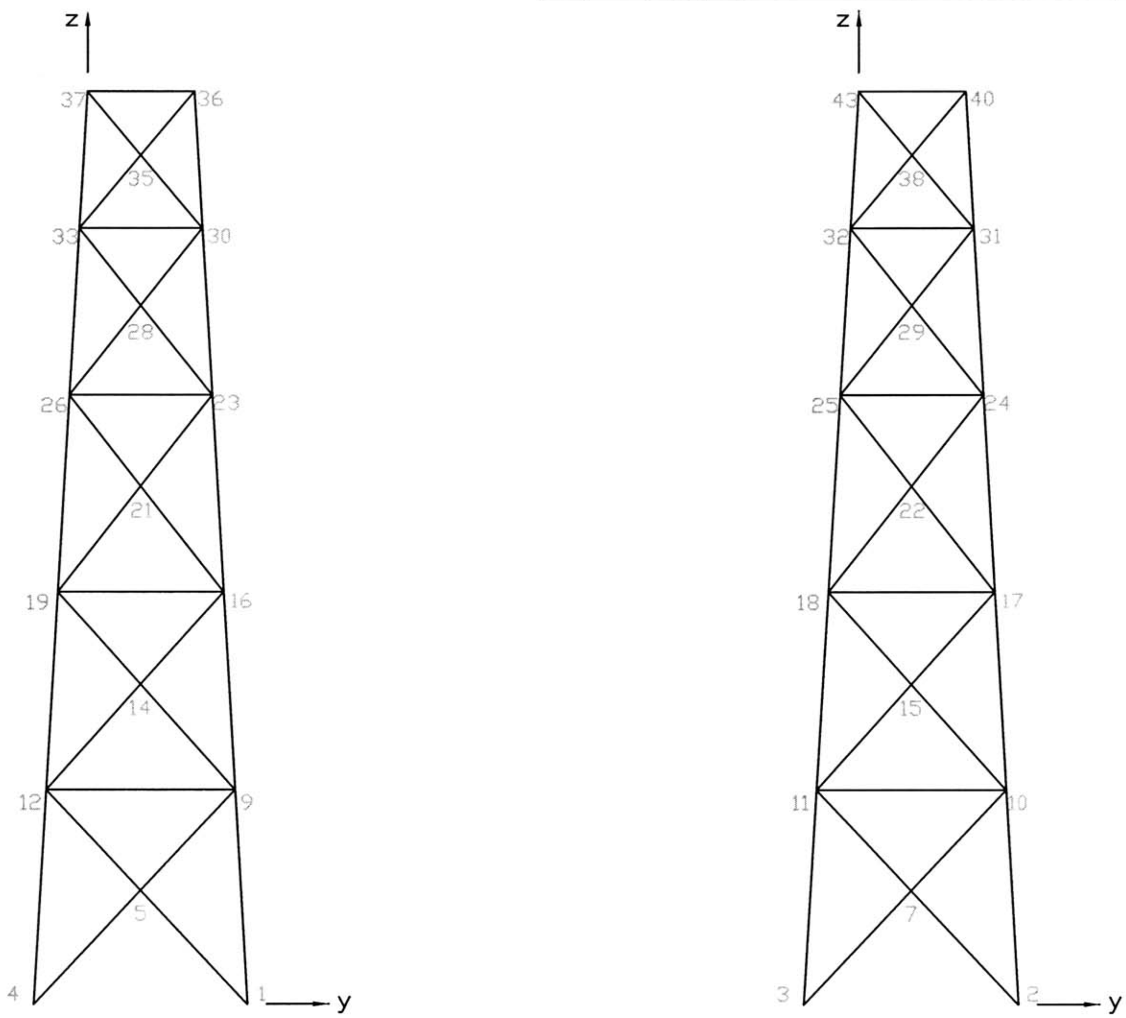


MATERIAL PROPERTIES

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$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43,500$ psi

| | | | |
|---|---|---|---|
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| | CHECKED BY: VERIFIE: DR.T.S.KOKO | | MATERIAL: MATERIAU: XS STEEL |
| | DRAWN BY: DESSINE PAR: T.E.DUNBAR | DESCRIPTION: MAST – SIDE VIEWS | PROJECT: PROJECT: 61013 |
| | SCALE: ECHELLE: 1:75 | | |
| UNLESS OTHERWISE NOTED UNITS: UNITES: INCHES | DATE: 07 FEB 2003 | DRAWING NUMBER: NUMERO DE DESSIN: | SHEET FEUILLE 5 OF DE 7 |

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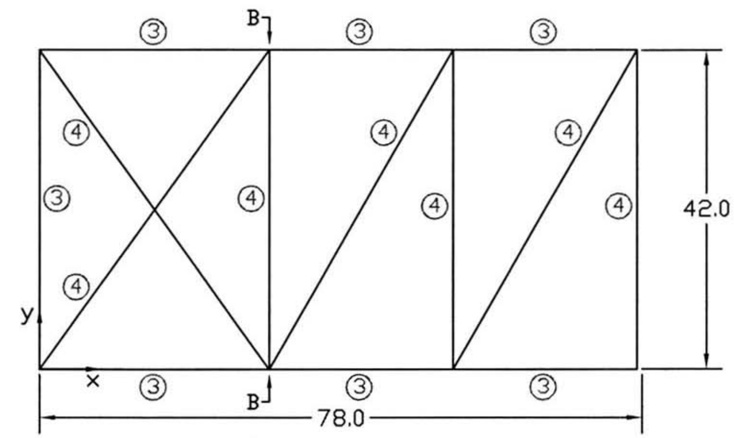
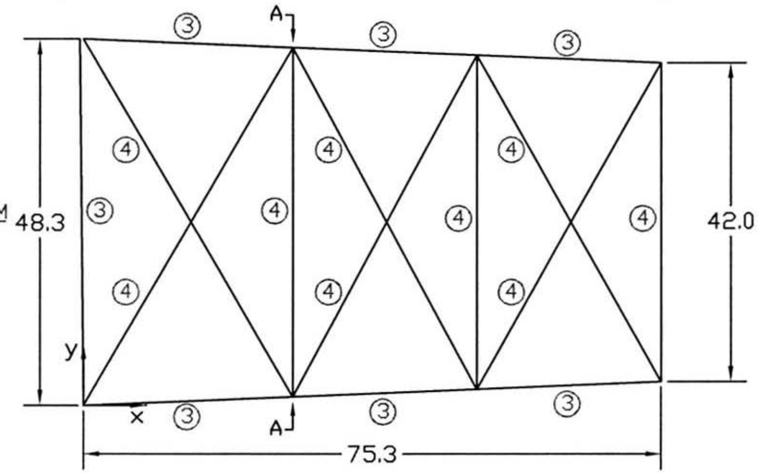
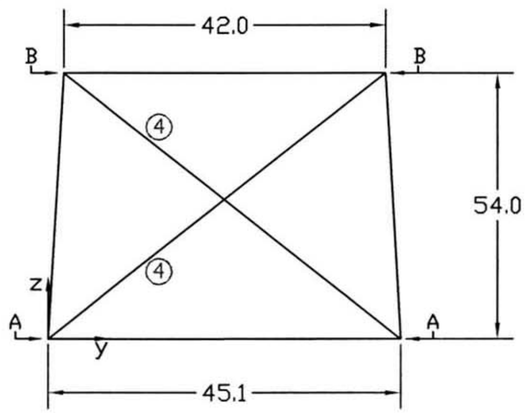



TOP
VIEW




BOTTOM
VIEW

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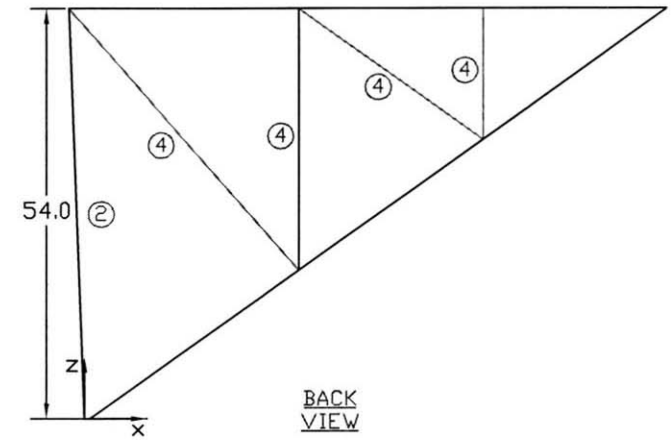
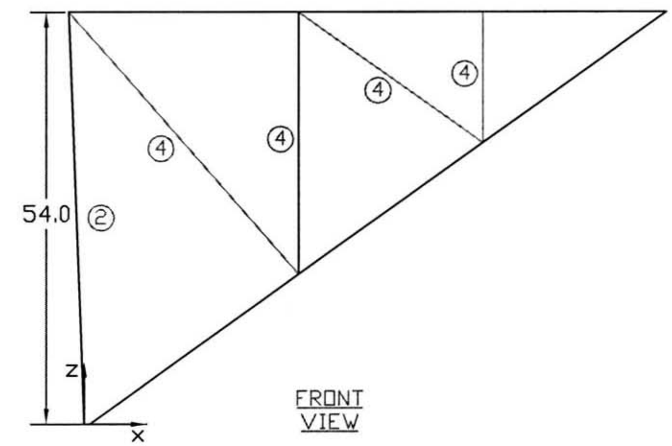
VIEW




BACK
VIEW




FRONT
VIEW

MATERIAL PROPERTIES

$E = 29.6 \times 10^6$

$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43{,}500$ psi

MEMBER DIAMETER (OD)
AND THICKNESSES (T)

① - 4" (OD)
- 0.318" (T)

② - 3 1/2" (OD)
- 0.300" (T)

③ - 2 7/8" (OD)
- 0.276" (T)

④ - 2 3/8" (OD)
- 0.218" (T)

| | | | |
|---|---|---|---|
| TOLERANCES: | APPROVED: APPROVE: | MARTEC LTD<br>1888 BRUNSWICK STREET, SUITE 400<br>HALIFAX, NS, B3J 3J8, CANADA | SIZE: GRANDEUR: / QUANTITY: QUANTITE: |
| | CHECKED BY: VERIFIE: DR.T.S.KOKO | | MATERIAL: MATERIAU: XS STEEL |
| | DRAWN BY: DESSINE PAR: T.E.DUNBAR | DESCRIPTION: YARDARM | PROJECT: PROJECT: 61013 |
| UNLESS OTHERWISE NOTED UNITS: UNITES: INCHES | SCALE: ECHELLE: 1:25 / DATE: 07 FEB 2003 | DRAWING NUMBER: NUMERO DE DESSIN: | SHEET FEUILLE 6 OF DE 7 |

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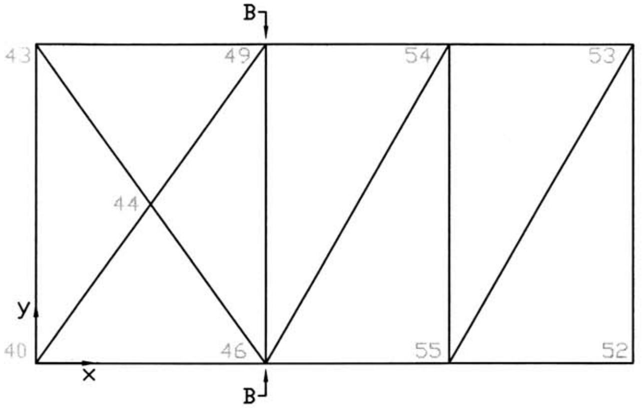
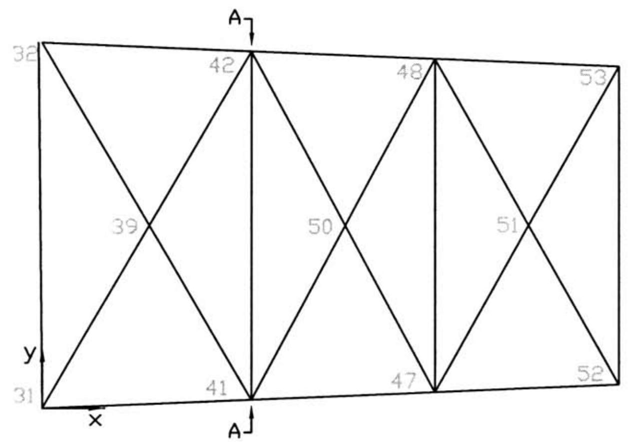
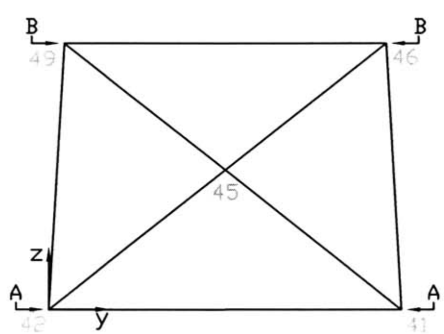
TOP VIEW

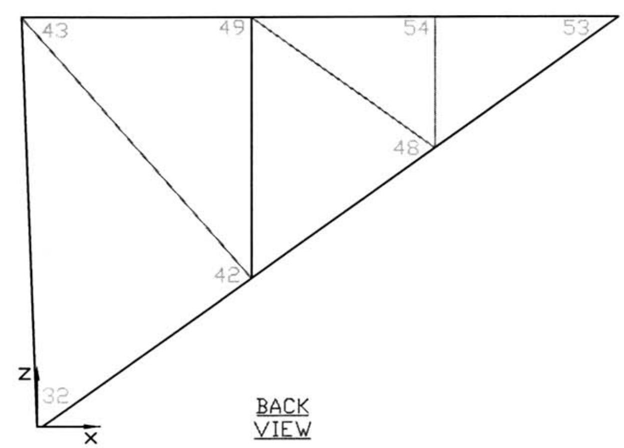



BOTTOM VIEW

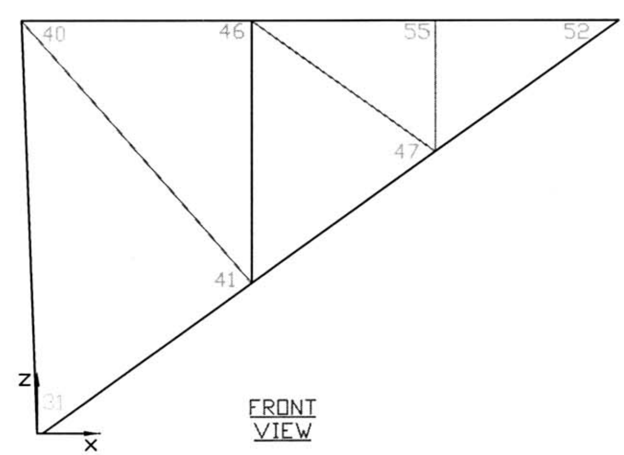



SECTION VIEW




BACK VIEW




FRONT VIEW

MATERIAL PROPERTIES

$E = 29.6 \times 10^6$

$\rho = 0.733 \times 10^{-3}$

$\upsilon = 0.30$

$\sigma = 43{,}500$ psi

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MATERIAL: MATERIAU: XS STEEL

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MASTSAS (MAST Structural Analysis Software) is a special-purpose, PC based computer program for rapid finite element modeling of warship mast structures. The MASTSAS software was developed under contract to DRDC Atlantic, using its HOOD (Hierarchical Object Oriented Database) toolkit. This Examples Manual, one of a series of three manuals documenting the MASTSAS software, provides a set of sample models and analyses that demonstrate the capabilities of the MASTSAS system.

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Mast
Ship structure
Finite element modeling
Composite structure
HOOD
Object oriented programming

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